NAVSHIPS 250-341-3

PRINCIPLES OF RADIATION AND CONTAMINATION CONTROL

VOLUME ONE

RADSAFE FOR EVERYBODY

BUREAU OF SHIPS NAVY DEPARTMENT WASHINGTON 25, D. C

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BUREAU OF SHIPS NAVY DEPARTMENT WASHINGTON 25, D. C

prepared by

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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ACKNOWLEDGEMENT

We have received so much help from many persons working in many places throughout the years we have been compiling this book that it would take another book to list them. To every one of them our sincerest thanks.
To any of them whose **words** we have paraphrased or whose statistics we have lifted without specific acknowledgement - our apologies along with our thanks.

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PRINCIPLES OF RADIATION AND CONTAMINATION CONTROL

(PORACC)

This series of three volumes on the control of radiation and radioactive contamination originated in a field manual developed for the naval participants in nuclear weapons tests at the Pacific Proving Grounds. Thinking that it might be more widely useful, it has been revised somewhat and divided according to "need to know" of the potential readers. The subject matter is presented more completely as the reader progresses from one volume to the next. The scientific foundation, i. e., the nuclear physics and radiobiology, are developed only to the extent needed in facing the practical problems.

The scope of the three volumes is primarily limited to non-wartime situations, although some of the material would, of course, be applicable to wartime use. For guidance under tactical situations, the reader is referred to such publications as Bureau of Ships Manual, Chapter 90, Nuclear Protection, the Radiological Recovery Manual TP-PL-13 and other similar publications.

Volume 1 is for persons working where there is radiation or using radioactive materials. It contains a general introduction to the physics of radiation and the biological effects that make it dangerous to health, together with techniques for measuring radiation and minimizing the chances that it will injure anyone. It should by itself meet the essential requirements of many persons.

Volume 11 is for those with special responsibility in regard to radiation, especially radiological monitors. It develops in more detail the fundamentals given in Volume 1.

Volume 111 contains data needed to conduct training courses for which Volume 11 might serve as a textbook. It should be referred to when what is given in Volume 1 or even in Volume 11 seems insufficient.

VOLUME 1

RADSAFE FOR EVERYBODY

Preface

This volume is designed to provide the knowledge about the dangers of radiation and their avoidance that every person ought to have for his own safety. Nuclear physics and biology are set forth sufficiently to show the scientific foundation for the required technology (called Health Physics) and the medical aspects (Radiation Hygiene). The necessary instruments and procedures are described for detecting radiation and estimating the degree of hazard. Methods are outlined for handling radioactive materials safely and for decontamination of personnel and equipment.

Volume 1 could serve as a training primer in a general radsafe indoctrination course for all Naval and Shipyard personnel. It is designed to provide a basis for a better understanding of radiological safety regulations and rules that underlie radiation hygiene. It is helpful to the primary user of this material to be supervised in radiological health matters by the Health Physicist or other persons with advanced training.

VOLUME 1

RADSAFE FOR EVERYBODY

Contents

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RADSAFE FOR EVERYBODY

SIGNIFICANCE OF ATOMIC ENERGY

Fusion Fallout Nuclear Istopes Radioactivity Gamma

Reactor Physics X rays

.. . . . . Are these simply scientific terms, terms which have meaning to scientists only? Not any longer. These terms and others similar to them were once associated only with nuclear science, but more and more they are being accented in our every-day conversation and living.

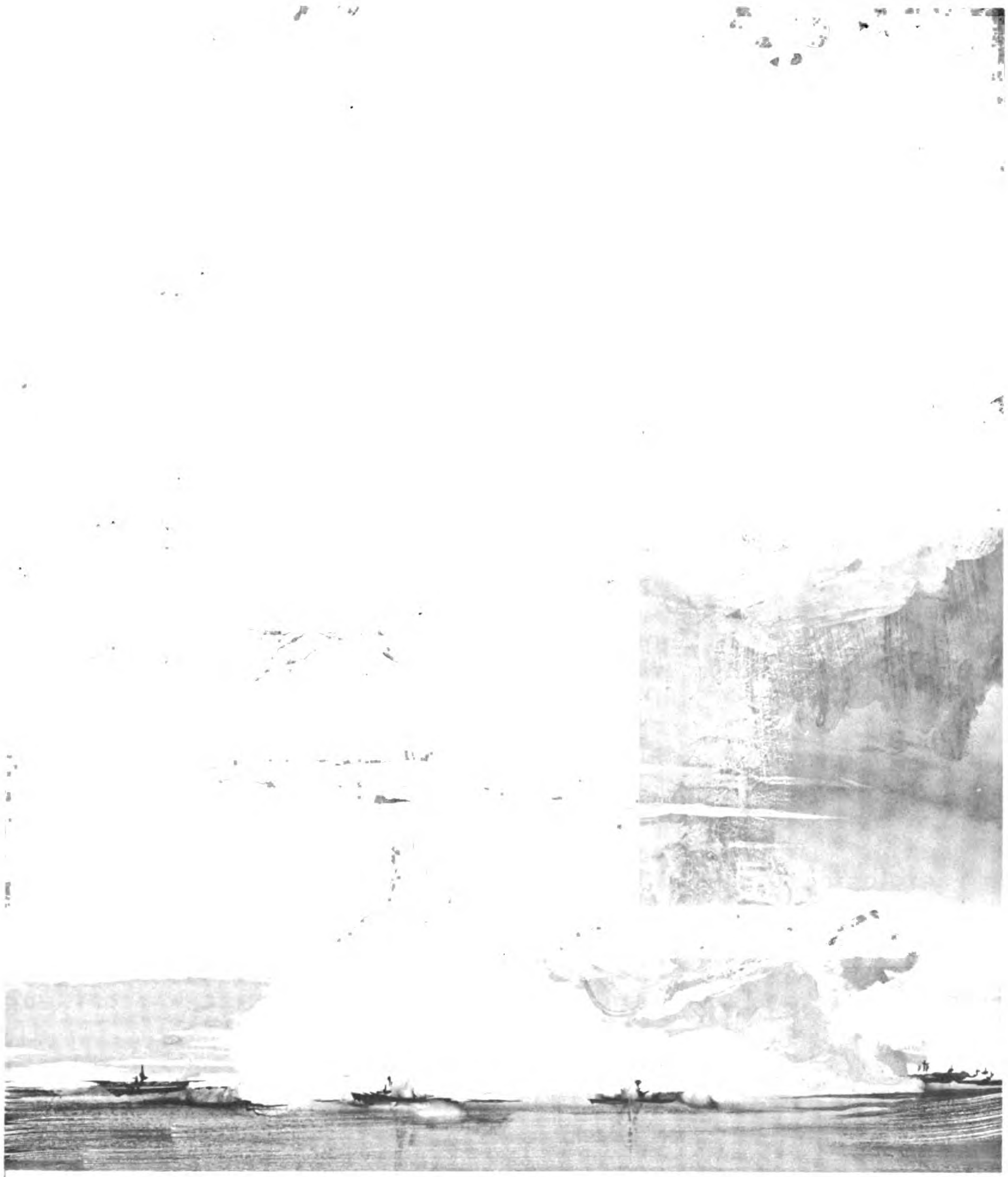
Just what do these terms really mean from the viewpoint of the average civilian or the man in uniform? What does he need to know in the growing field of nuclear physics and nuclear engineering? What more must he know to function efficiently as a radiological monitor?

This manual has been designed to be practical, informative, and useful, to help fit that "average" civilian or man in uniform into his all-important role as a citizen of the atomic age.

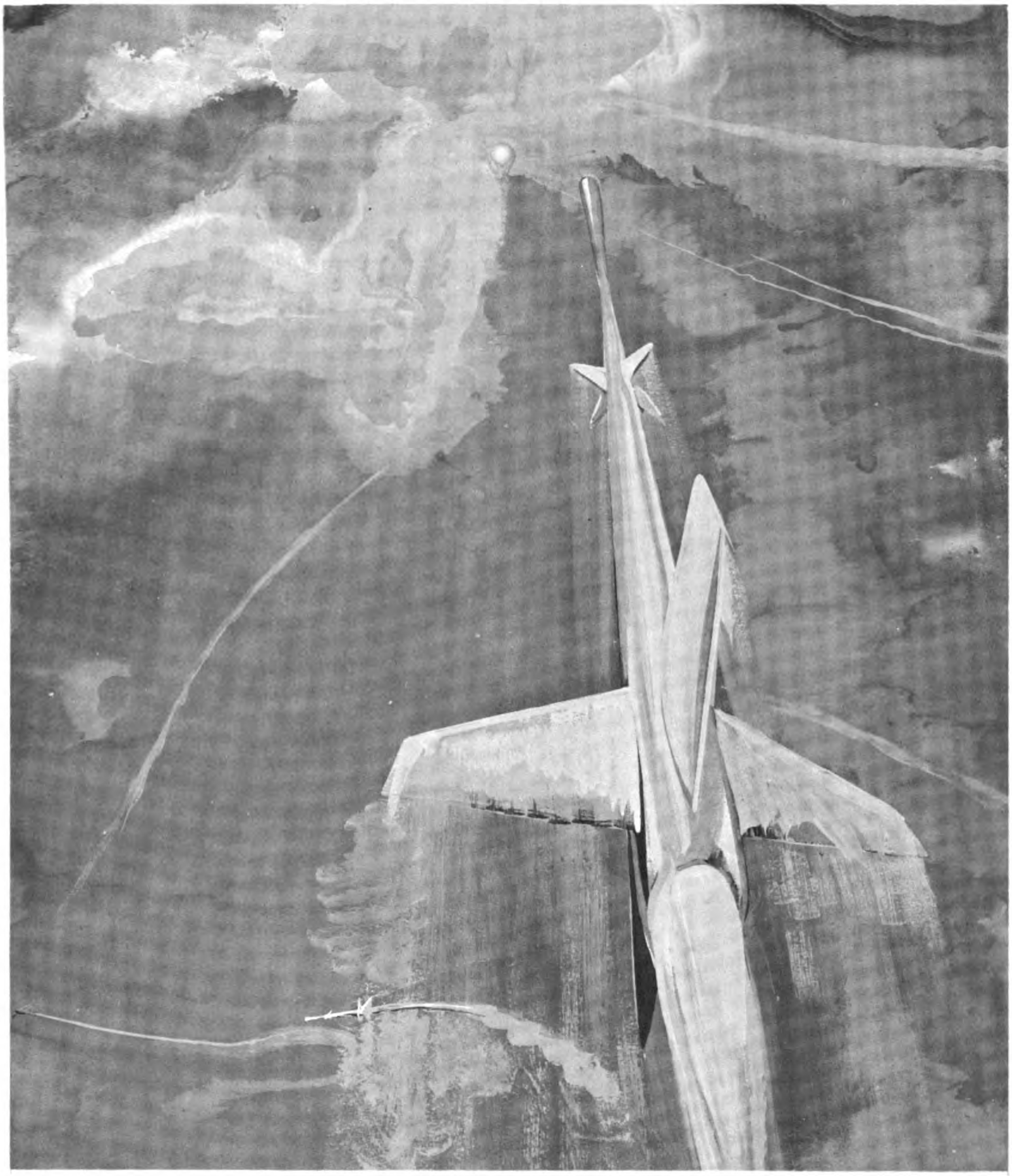
Man lives in a world of phantom energies. Fear and ignorance go hand in hand. Knowledge and a logical approach will dispel fear.

Radiation is a type of energy. Many kinds of radiation travel through materials and surrounding space, UNSEEN, UNHEARD, UNFELT, without TASTE or SMELL.... UNDETECTED by the five senses of man.

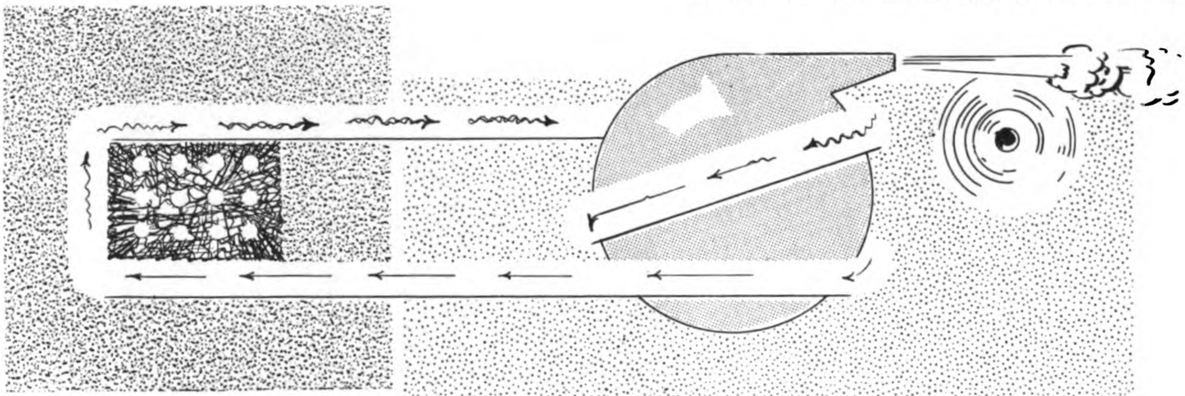
WHERE do such radiations originate? HOW do they affect him? WHAT can be done to detect them and live with them in SAFETY?



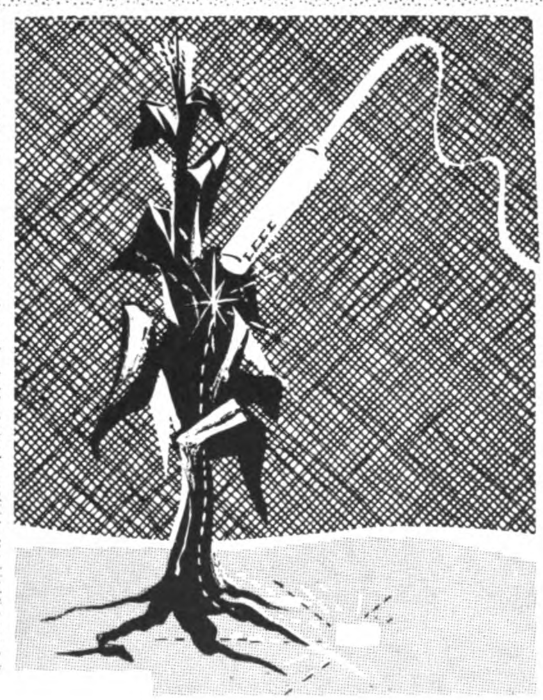
Though atomic energy has vital significance for National Defense, it has uses far beyond those of military application.



In addition to the use of nuclear weapons, both strategic and tactical, it should be recognized that X-ray machines have long been used as a source of radiation. Furthermore, atomic energy is becoming increasingly important in the fields of industrial power, agricultural research, and in production quality-control processes.

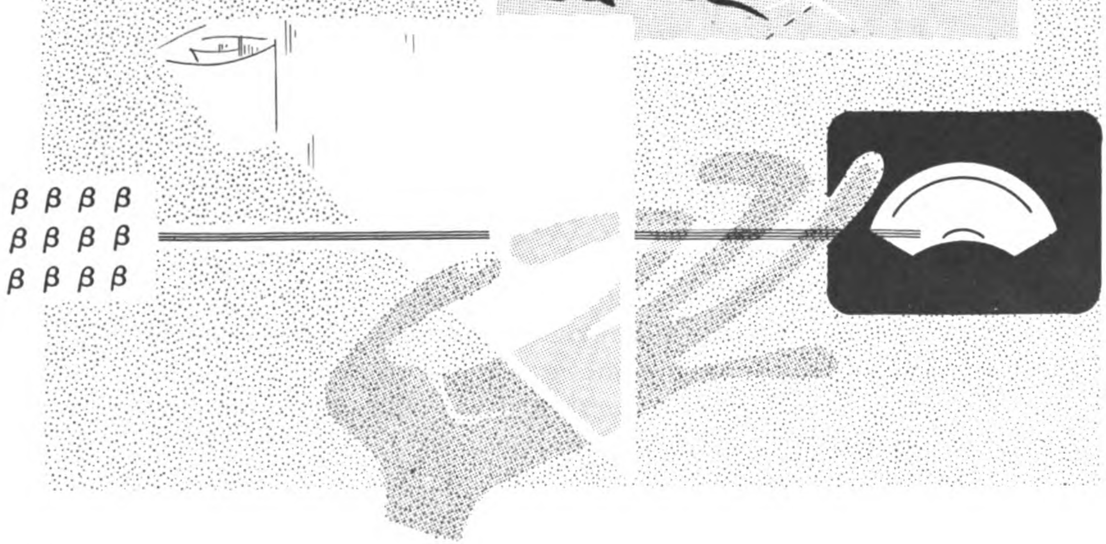


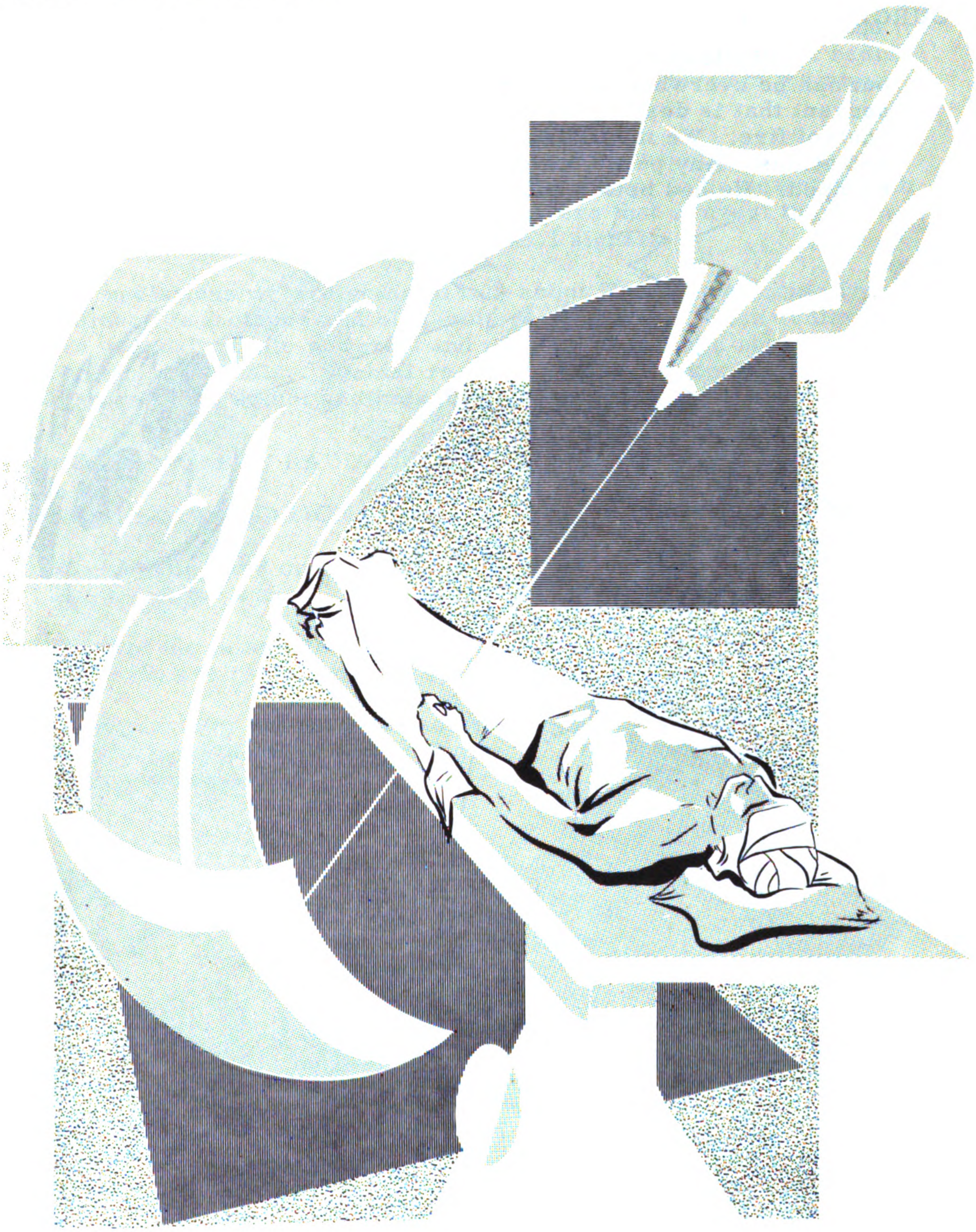
INDUSTRIAL POWER
controlled fission



AGRICULTURAL STUDIES
radioactive tracers

QUALITY CONTROL
radiation absorption

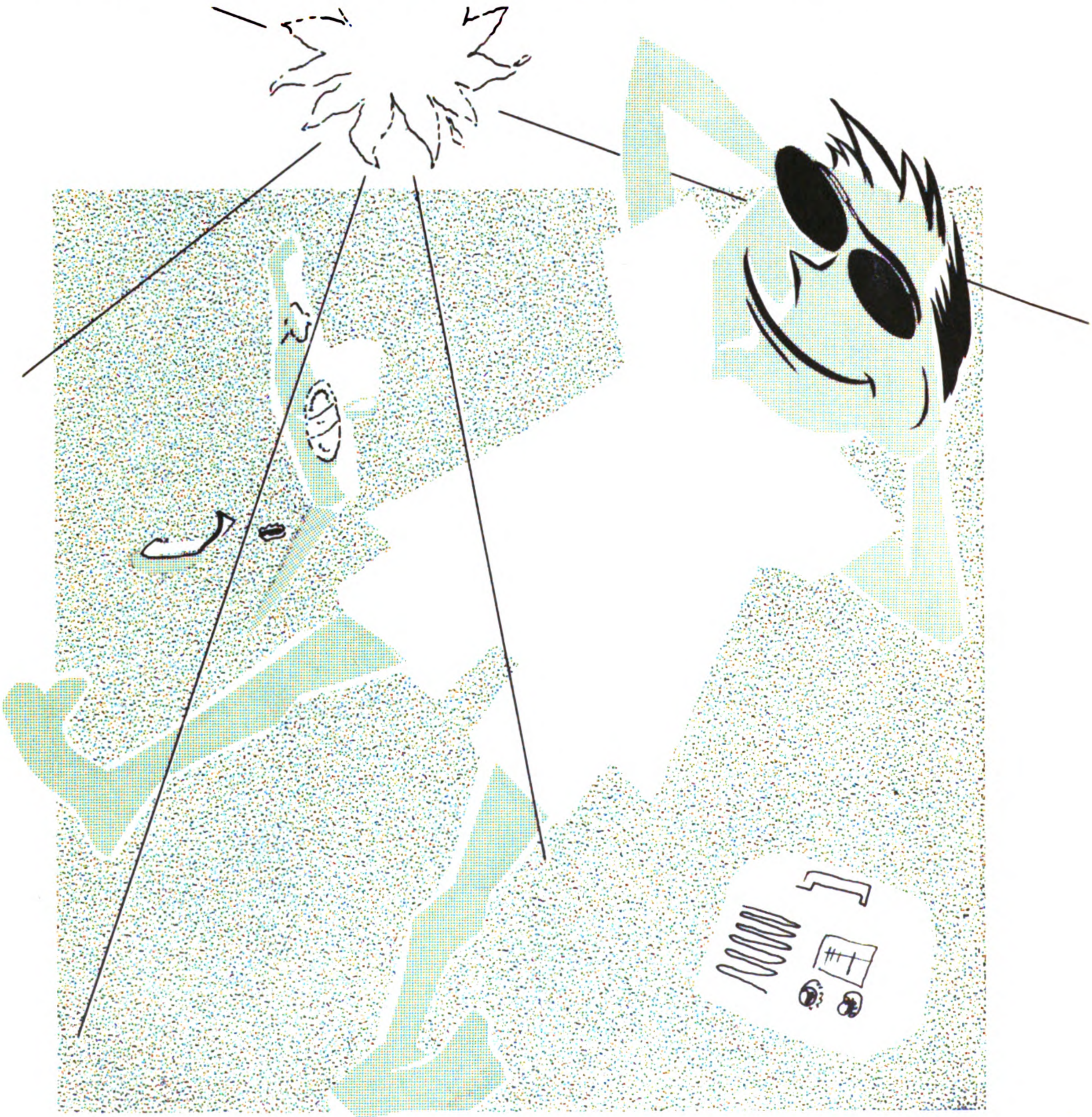




β γ and neutron irradiation sources **MEDICAL TREATMENT**

SOURCES OF RADIATION

Nuclear energy can be one of man's greatest servants, but can be overwhelmingly destructive. Fire, too, is a good servant that is destructive when it gets out of control. We do control fire. We must also control nuclear energy and its radiations. Any person might have to face radiations that have escaped. He had better know what to do and how to do it.



SUNSHINE is RADIATION too.

RADIATION is energy. It may come from various sources and it may assume various forms. The sun produces ultraviolet radiation which travels through air and enough gets through the atmosphere to produce a sunburn.

Radio, TV and radar waves are types of radiation coming from transmitting antennae. These radiations have to be detected with radio receivers or TV or radar receivers that convert the transmissions into audible signals or visual signals.

The radiations we are going to talk about in this book come from radioactive isotopes and high-voltage machines. Such radiations are generally quite powerful and can travel through space and all kinds of materials. Special receivers called radiation instruments are needed to detect and measure these radiations.

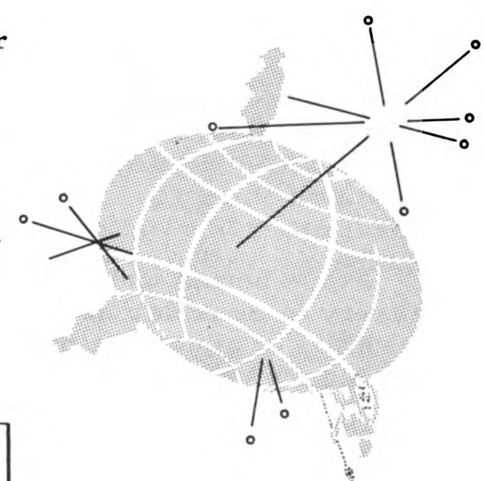
WHAT KINDS OF RADIATIONS ARE THERE?

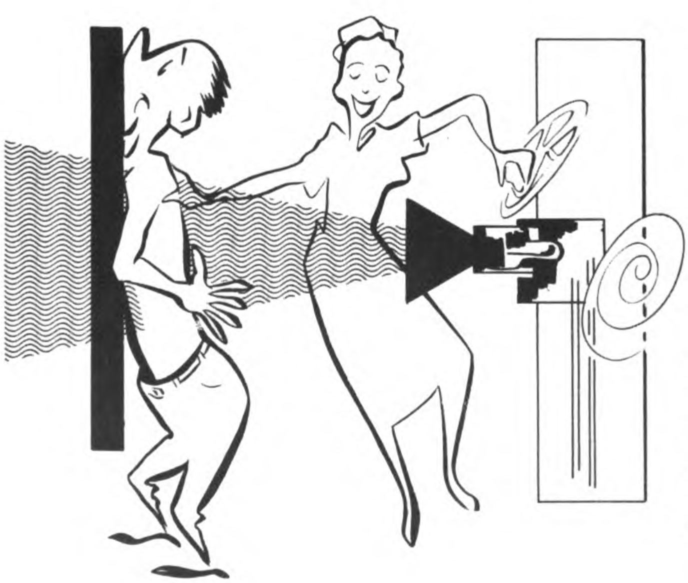
NATURAL RADIATION

The cosmic rays come from outer space and the sun.

Some of the minerals making up the earth are radioactive.

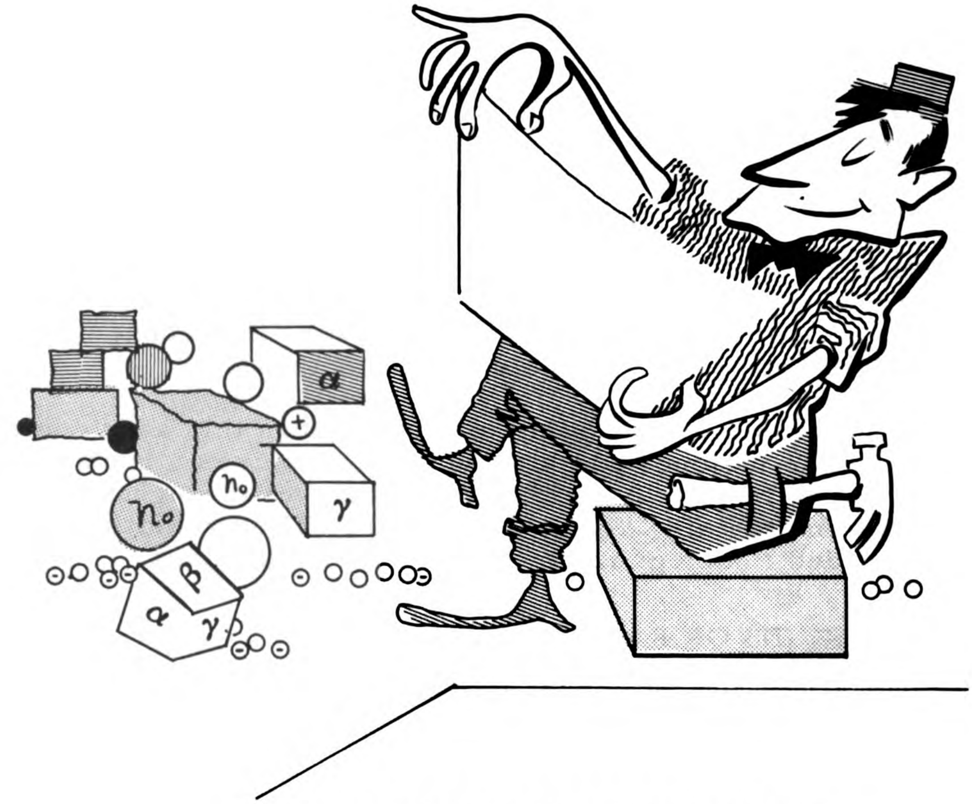
There are tiny amounts of radium in the air we breathe and in some spring waters.





MAN MADE RADIATION

X rays and the radiations from atomic bombs, many radioisotopes, nuclear reactors, cyclotrons, etc.



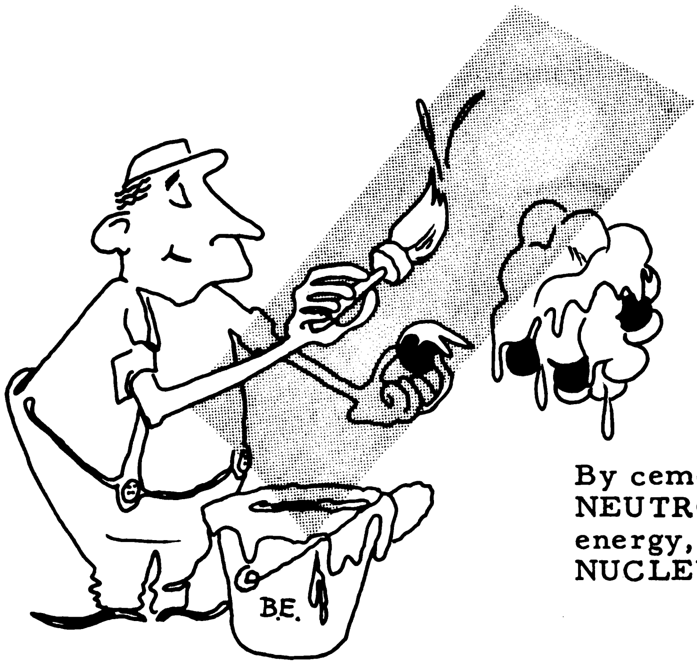
ATOMIC AND NUCLEAR STRUCTURE

For a better understanding of the sources of radiation, it is necessary to consider how all the world is put together. The smallest units of construction of the world in which man lives, the "building blocks" of the universe, are:

p — **PROTONS,** tiny particles of matter with a positive electrical charge

n — **NEUTRONS,** similar but with no electrical charge

β — **ELECTRONS,** which are negatively charged particles. The weight of an electron is only about 1/2000th that of a proton or neutron.



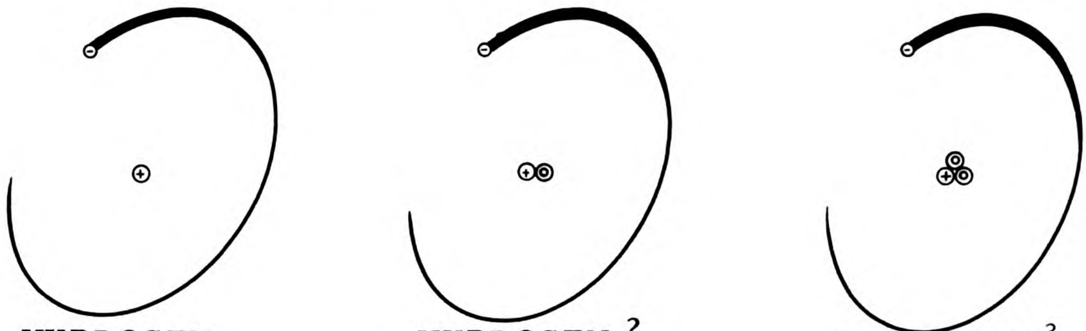
By cementing PROTONS and NEUTRONS together with binding energy, we get an ATOMIC NUCLEUS.

The NUCLEUS has to have a certain balance of neutrons and protons to make it STABLE. Otherwise the binding energy can't hold them. Sooner or later such an UNSTABLE NUCLEUS will DECAY spontaneously.

The ATOM is finished by adding ORBITAL ELECTRONS to equal the number of protons in the nucleus. Each negative electron neutralizes the positive charge on one proton, so that the whole atom is electrically neutral.

Compared to the electron orbits, the NUCLEUS is amazingly small - about like a fly in the middle of a football stadium. It's heavy though, for it accounts for almost all the weight of the atom.

Atoms with a particular number of nuclear protons make an ELEMENT. More than 100 elements are known, including the unstable manufactured ones.



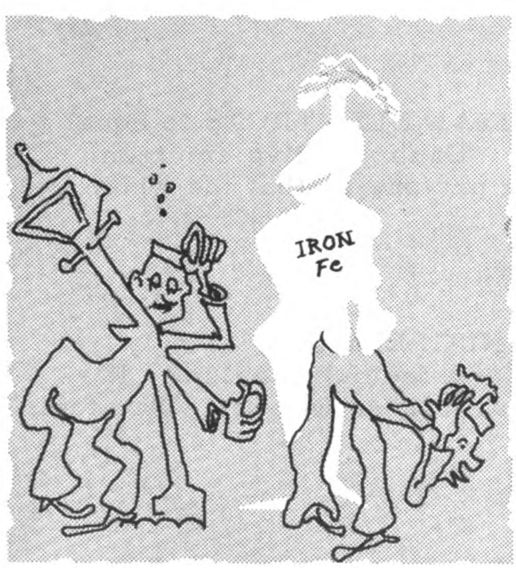
HYDROGEN — 1 proton

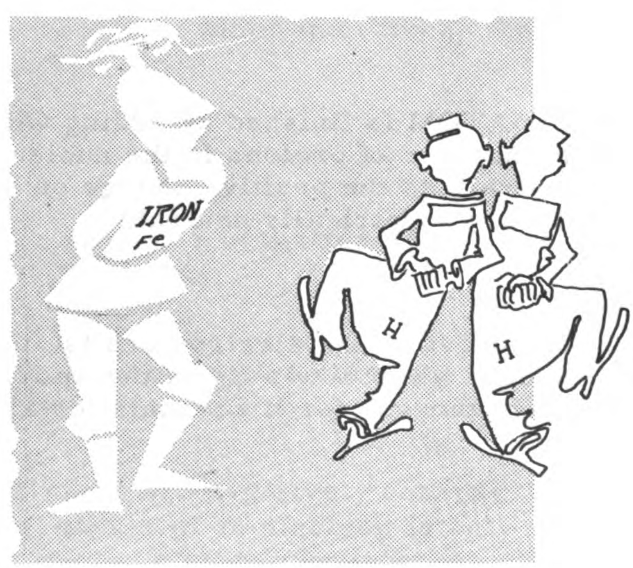
HYDROGEN ^{2} — 1 proton, 1 neutron

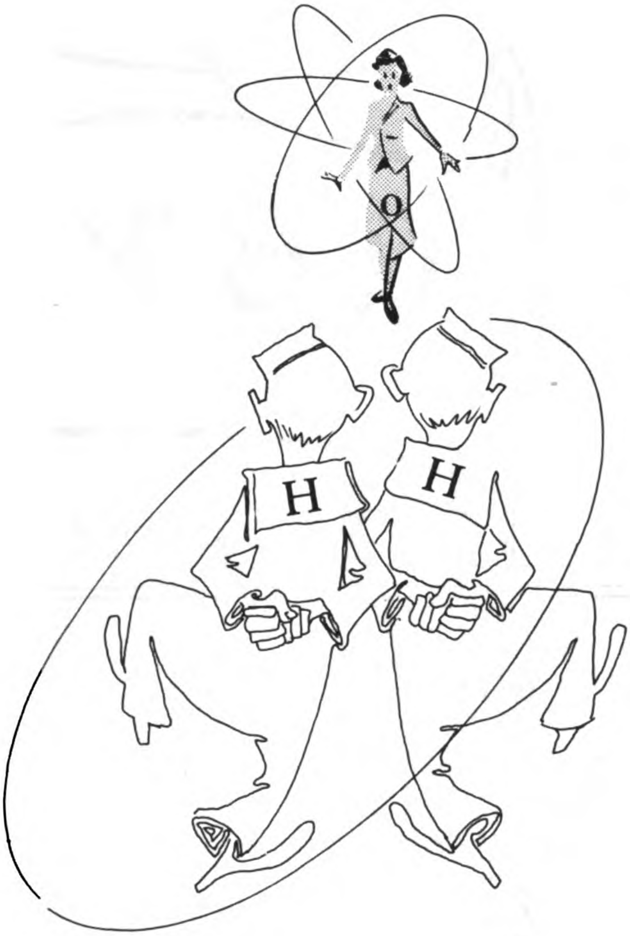
HYDROGEN ^{3} — 1 proton, 2 neutrons

Every element has several ISOTOPES, all having the same number of nuclear protons (characteristic of that element), but with different numbers of neutrons. There are more unstable isotopes than stable ones. Some elements have only one stable isotope; some haven't any.

Most atoms don't seem able to stand by themselves very long. They hitch up with other atoms of their own kind or of other kinds to form MOLECULES. For example, two atoms of hydrogen (H) make a molecule of hydrogen. An atom of iron might join a regiment of solid iron (iron crystal) or look about for some oxygen (O) and hydrogen atoms to combine with (iron rust).







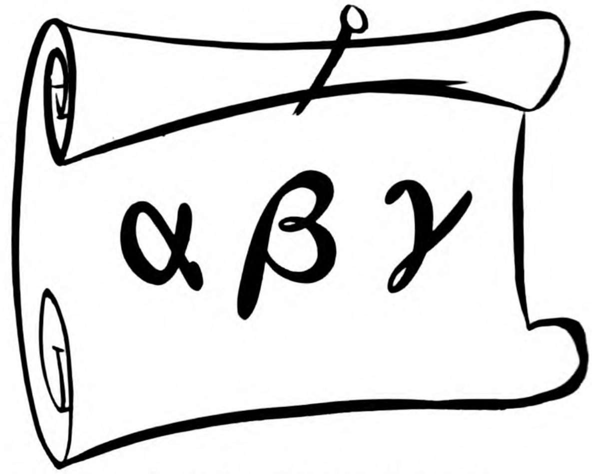
MOLECULES

When the atoms in a molecule are different, we call it a CHEMICAL COMPOUND. When the atoms are all the same, they make molecules of the free ELEMENT. Hydrogen gas is a free element. It readily combines with oxygen to make water, a chemical compound.

MATTER

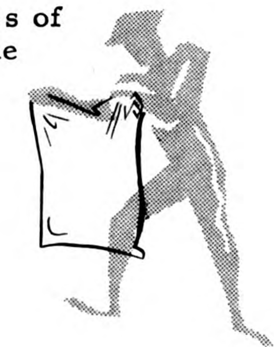
Matter is stuff that has weight. Dirt, liquids, gases, and crystals - all kinds of molecules and atoms and the neutrons, protons and electrons they're made of - are all MATTER.

When UNSTABLE atoms DECAY, nuclear RADIATION comes out. Then you have a new atom, which may be stable or may decay in its turn.



The radiation is made of PARTICLES. Nowadays even gamma rays and X rays are called particles even though they have no weight. When particles are going fast, they are called RAYS. LIGHT, X RAYS and GAMMA RAYS are all called PHOTONS. They all travel at the same speed (in a vacuum), which is the maximum speed possible - 186,000 miles / sec (3×10^{10} cm / sec).

ALPHA PARTICLES are the same as helium nuclei (two protons and two neutrons). They are emitted from the nuclei of certain radioactive elements. Because they carry two positive charges and are big and don't travel very fast, they are easily stopped by a sheet of paper or three or four inches of air. The Greek letter alpha, α, is used to represent the alpha particle.



α

BETA PARTICLES are negative electrons emitted from the nuclei of some radioactive elements. Because they are light, they have to travel fast to carry much energy. Because they carry an electric charge, they are scattered and stopped fairly easily. Except for the ones with high speed, ordinary clothing will usually do the job. The Greek letter beta, β, is used to represent the beta particle.

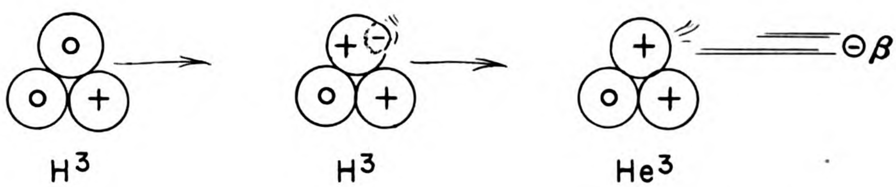
β

GAMMA RAYS are invisible bundles of energy emitted from the nuclei of certain radioactive elements. They differ from light and radio waves in having enormously higher vibration frequency (short wave length). Their energy increases as the wave length becomes shorter. They are very penetrating. That is why it may take such heavy shielding to give protection - inches of lead, iron or concrete, or several feet of earth or water. Of course, the farther away you are from the source, the fewer gamma rays reach you. X RAYS are the same as gamma rays except they come from outside the nucleus. The Greek letter gamma, γ, is used to represent the gamma ray.

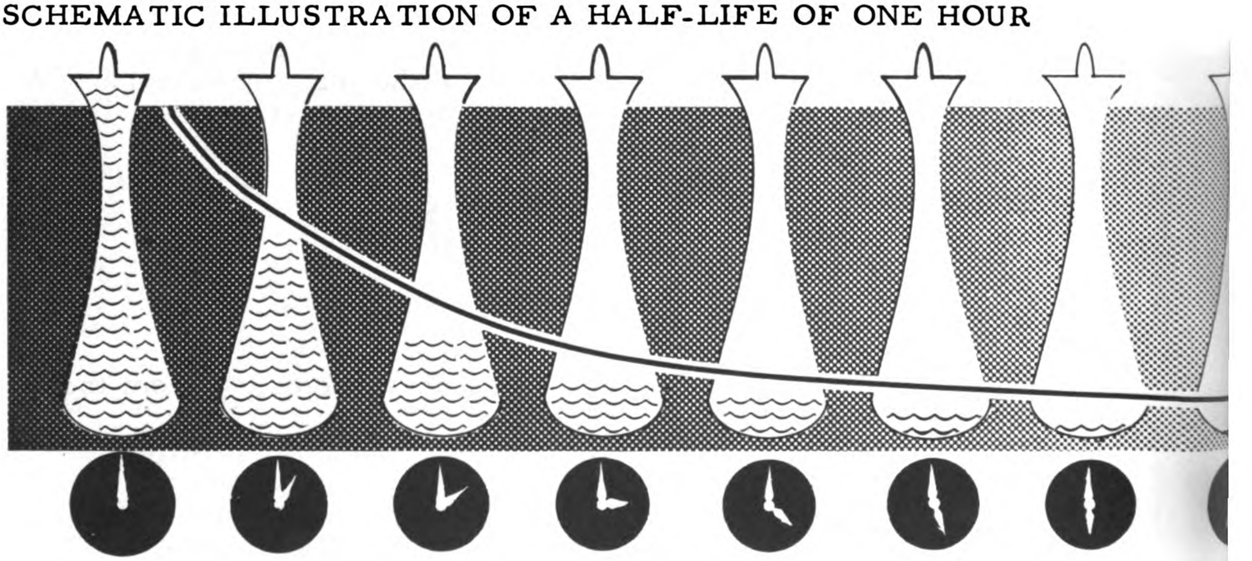
γ

RADIOACTIVITY

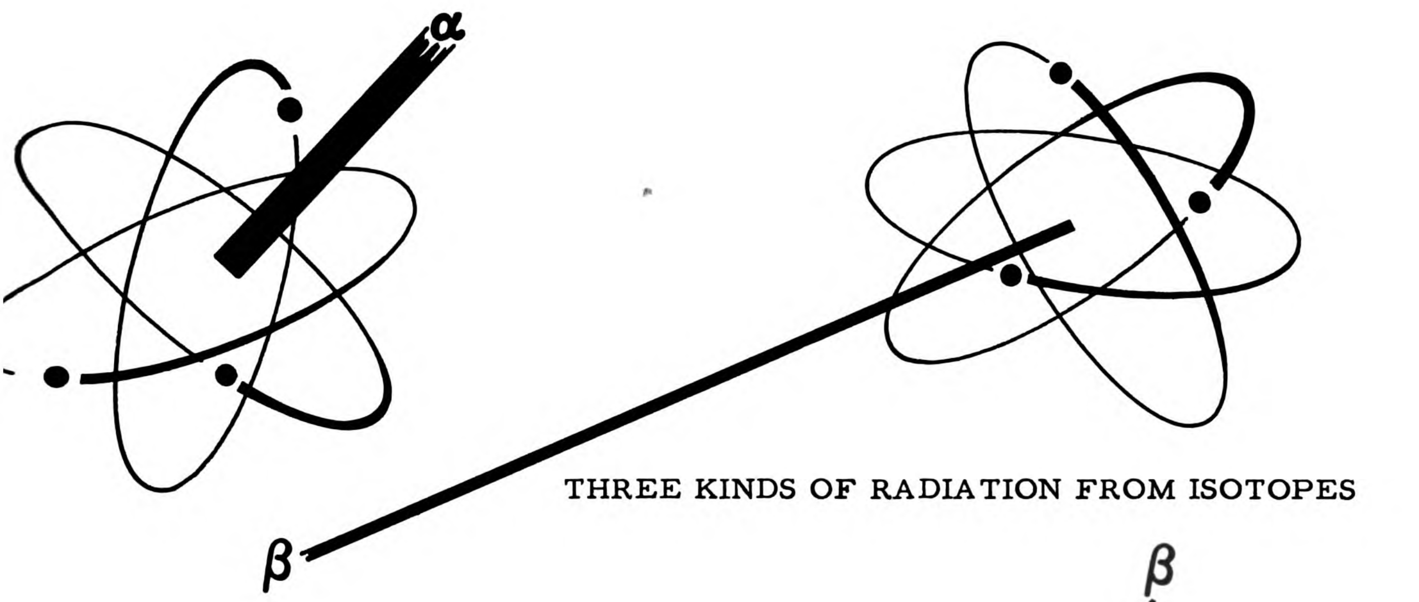
An unstable atom which changes to another atom and radiates energy. is a RADIOACTIVE ATOM. The new atom may be stable or unstable. This process is called RADIOACTIVE DECAY. For example, hydrogen-3 (one proton and two neutrons in the nucleus) decays to stable helium-3 by emitting a beta particle.



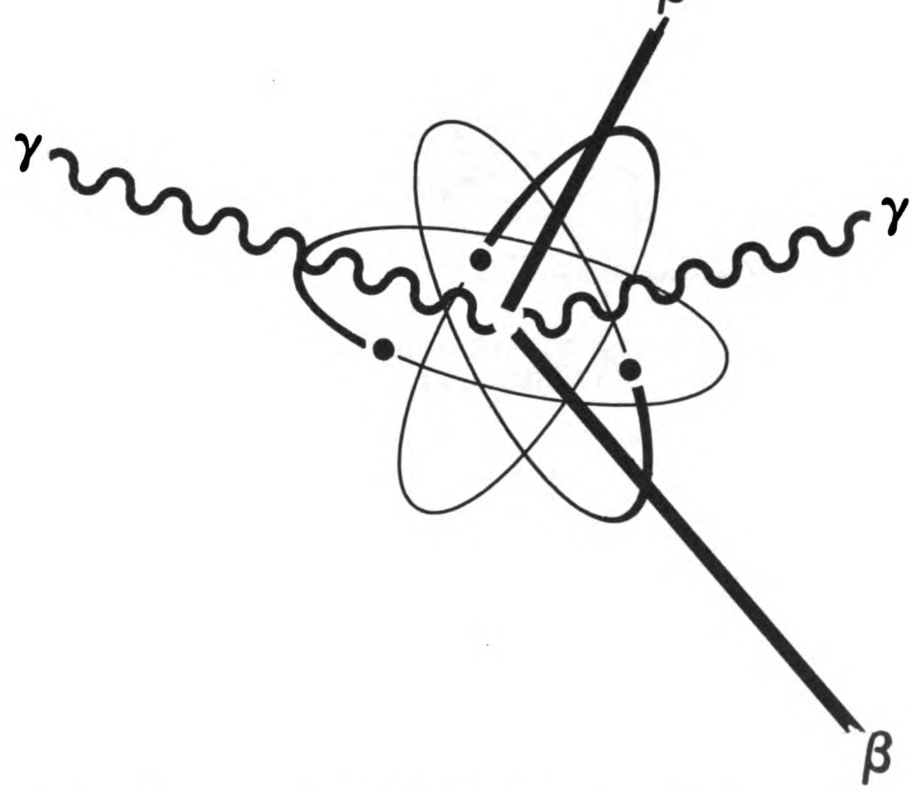
SCHEMATIC ILLUSTRATION OF A HALF-LIFE OF ONE HOUR

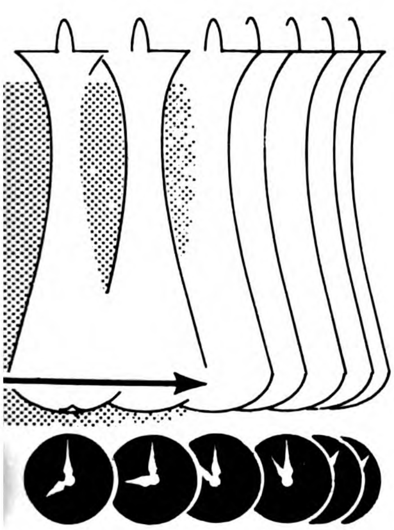


HALF-LIFE ($T_{1/2}$) is the time it takes for a radioactive sample to decay to half its original radioactivity. Some radioactive isotopes have half-lives measured in a tiny fraction of a second. Others are measured in billions of years. A short half-life means rapid decay. Suppose we start with a million atoms of iodine-131.



THREE KINDS OF RADIATION FROM ISOTOPES





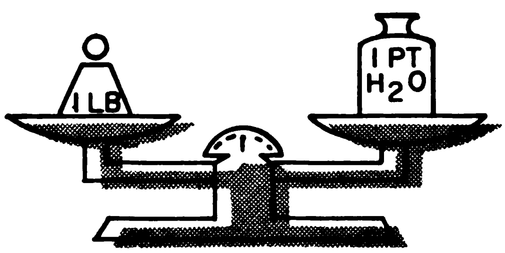
(This is a tiny fraction of a microgram.) In the first 8 days, half the atoms decay to xenon-131. After 16 days, only 1/4 or 250,000 atoms are left. After 80 days, only 0.1 per cent (less than 1000 atoms) remain. Finally we get down to the last couple of atoms and who can tell at what moment either of them will decay?

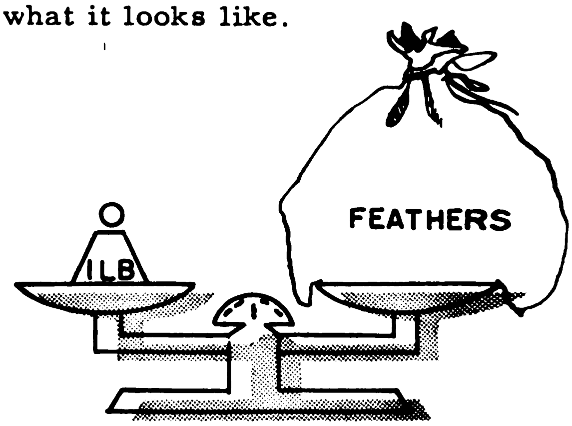
WEIGHT vs CURIE

The CURIE is that amount of radioactive material that disintegrates at the rate of 37 billion atoms per second. The longer the half-life ($T_{1/2}$), the more atoms it takes to provide a given amount of activity (because every disintegration transmutes an atom) and the longer the supply will last. Therefore, the half-life is a good measure of the rate of decay. The greater the chance of the atoms disintegrating (shorter $T_{1/2}$), the smaller the number of atoms required to produce a given amount of activity.

A POUND is a pound no matter what it looks like.

examples:

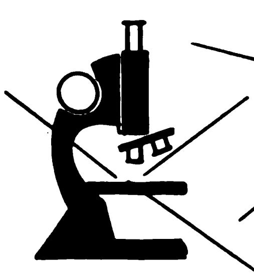




A CURIE must contain enough atoms to provide 37 billion atomic disintegrations per second.

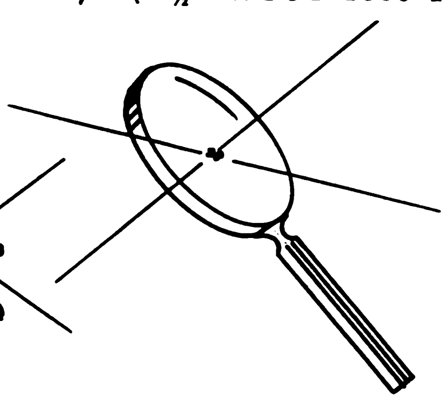
examples:

ONE CURIE La-140
($T_{1/2}$ ABOUT 2 DAYS)



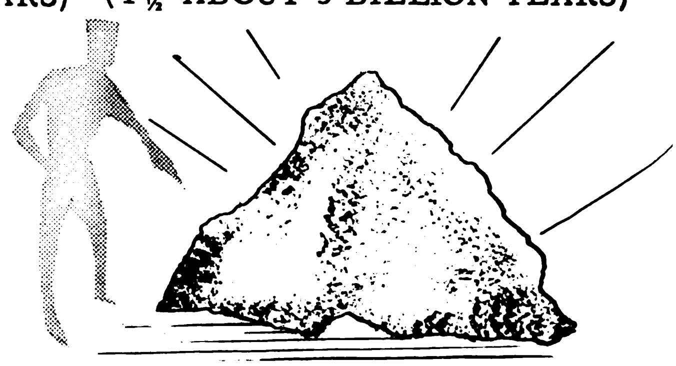
0.0000000006 ounce
(1.8 micrograms)

ONE CURIE Ra-226
($T_{1/2}$ ABOUT 1600 YEARS)



0.04 ounce
(1 gram)

ONE CURIE U-238
($T_{1/2}$ ABOUT 3 BILLION YEARS)

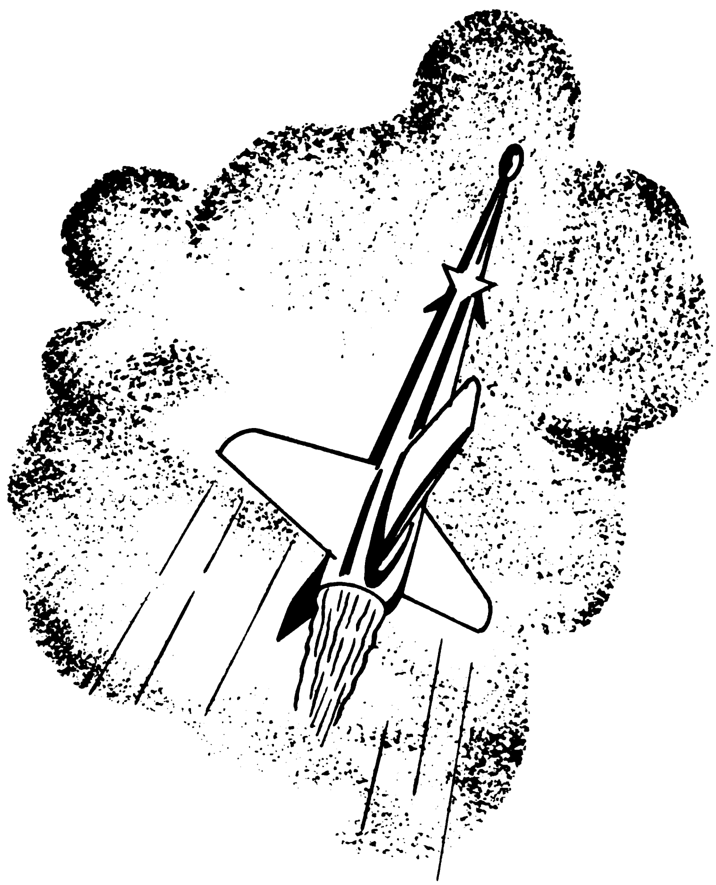


3 tons
(2,980 kilograms)

MEV

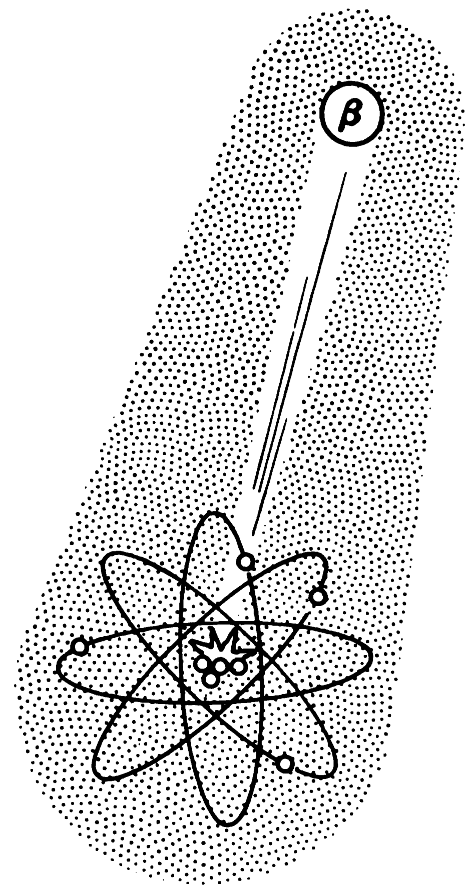
(KINETIC ENERGY)

THE ROCKET



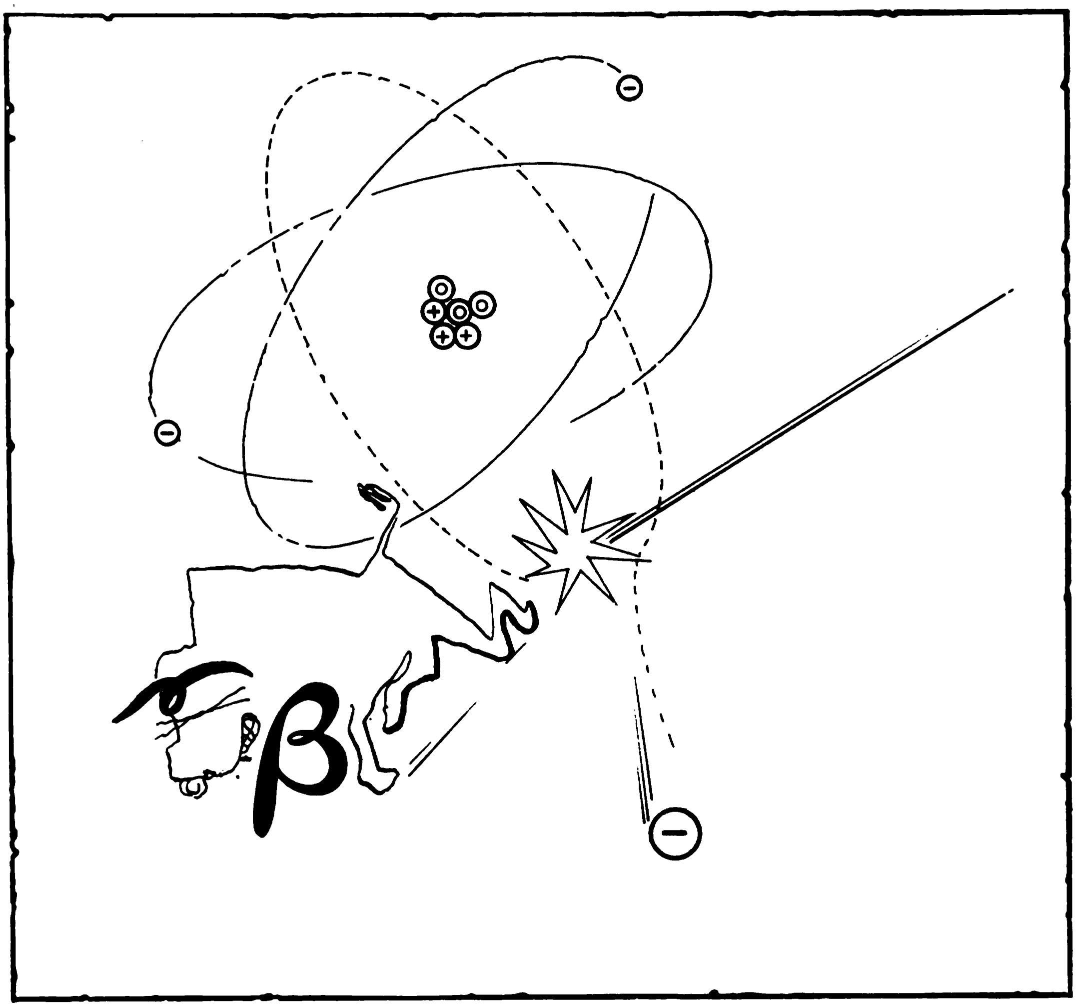
Energy measured in
FOOT POUNDS

THE BETA PARTICLE



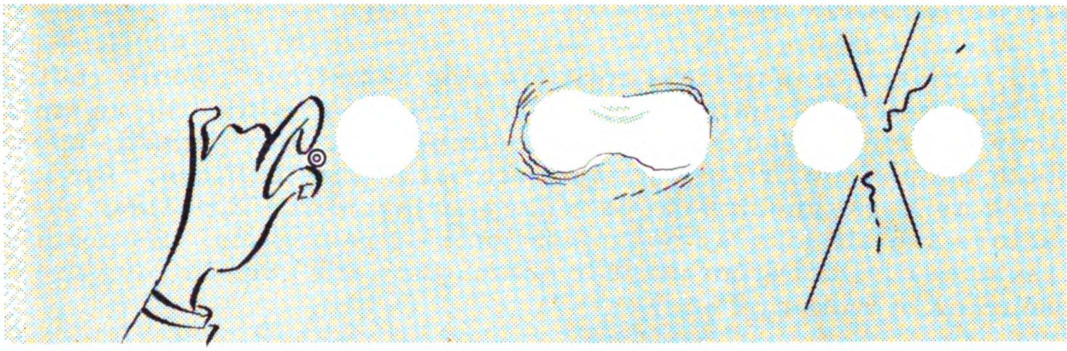
Energy measured in
ELECTRON VOLTS

As the energy of the rocket is measured in foot pounds, the kinetic energy of the beta particle (and other ionizing radiations) is measured in electron volts (ev) or in millions of electron volts (Mev).



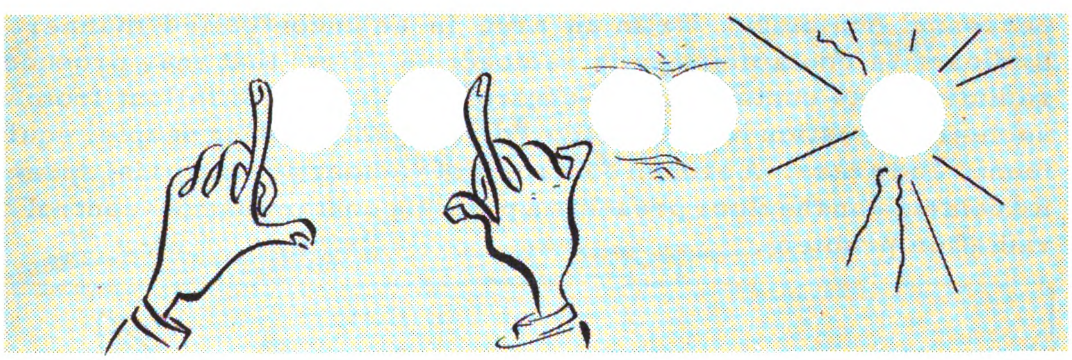
IONIZATION

If a normal, electrically-balanced atom loses or gains an orbital electron, it is then said to be ionized. Ionization can occur easily since orbital electrons are quite far away from their nucleus. For example, radiations travel through matter, stripping away orbital electrons from the atom. The atom is left with a positive charge. It has become a positive ion. The stripped-off free electron hitches on to a convenient atom, making a negative ion. Thus ions are formed in pairs (1 positive and 1 negative) and go on about their business until they meet an opposite charge and become electrically neutral atoms. Nuclear radiations always produce ionization and are therefore called IONIZING RADIATIONS.



FISSION is the process of splitting the nucleus of an atom. A few kinds of heavy atoms fission spontaneously. Some fission after absorbing a neutron. When fission occurs, the two new lighter atoms - called fission products - fly apart with a great deal of energy. Also, two or three neutrons may come out. If these strike other atoms of fissionable material, further fission may occur - - the CHAIN REACTION.

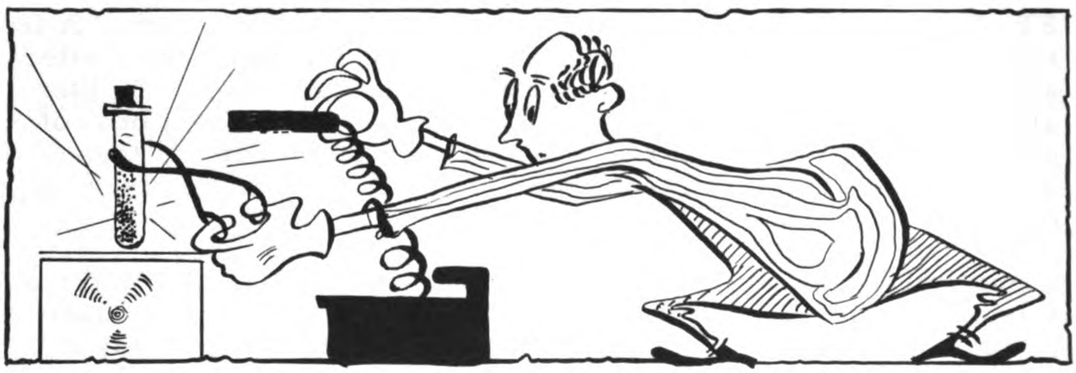
In nuclear reactors the rate of fission is CONTROLLED and the fission energy appears as heat which may be converted to useful power. In an atomic bomb detonation, the fission process is UNCONTROLLED and there is an instantaneous release of tremendous energy in the form of blast, heat, light, and nuclear radiations.



FUSION is the process wherein nuclei are joined together to form a new and heavier nucleus. The fusion we are interested in is the combining of hydrogen nuclei (the lightest atom) to form helium (the next heavier atom). A large amount of energy is produced. This is the reaction from which the sun gets the tremendous amount of energy that it radiates. The hydrogen bomb is a fusion bomb and can be made many times more powerful than the atomic, or fission bomb.

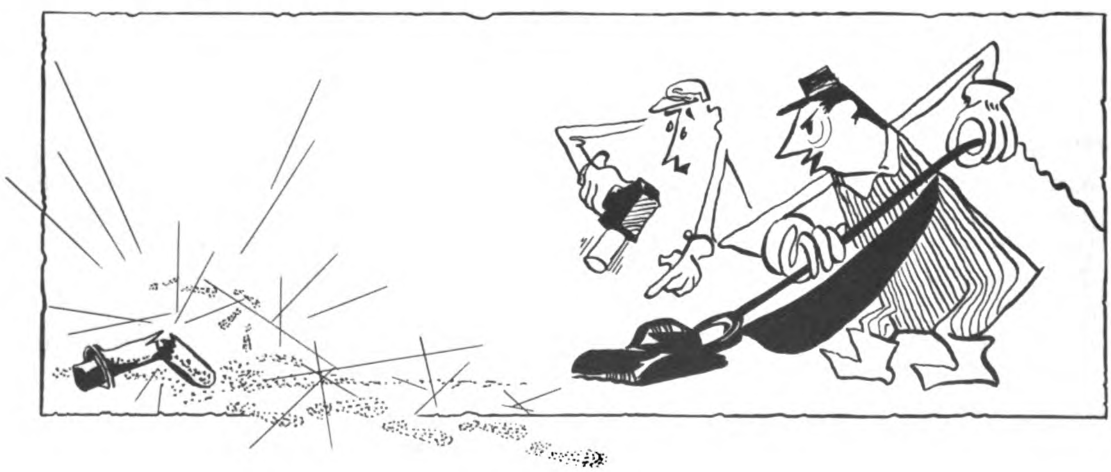
IONIZING RADIATION

All radioactive materials emit ionizing radiations. Some radioactive materials emit a mixture of **radiations** while others emit only one type. The intensity of ionizing radiations depends upon both the amount of radioactive material and its half-life. Devices such as X-ray machines, particle accelerators, and nuclear reactors are all sources of intense ionizing radiations. Radioactive isotopes, fallout from nuclear detonations and cosmic rays are also sources of radiation energy.



RADIOACTIVE CONTAMINATION

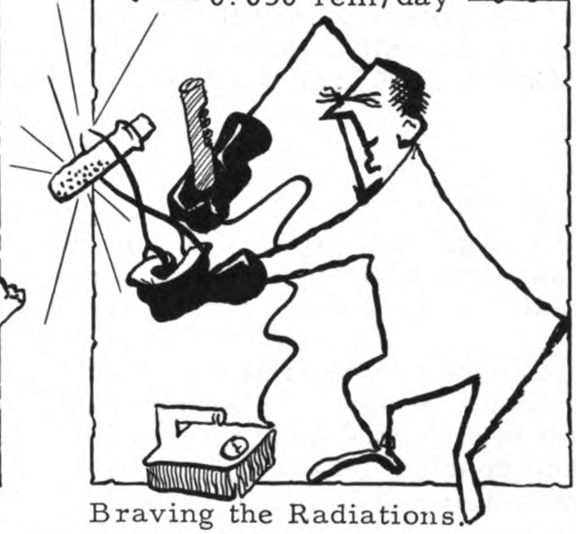
This consists of any undesirable radioactive material deposited on personnel, equipment, or in an area in an uncontrolled manner. Radioactive contamination is radioactive "dirt" that may produce a radiation plus contamination-control problem. The fallout from a nuclear detonation is radioactive "dirt" contaminating people, equipment, and areas. A broken container of radioactive material spreading its contents on the floor presents a possible contamination-control and radiation problem.



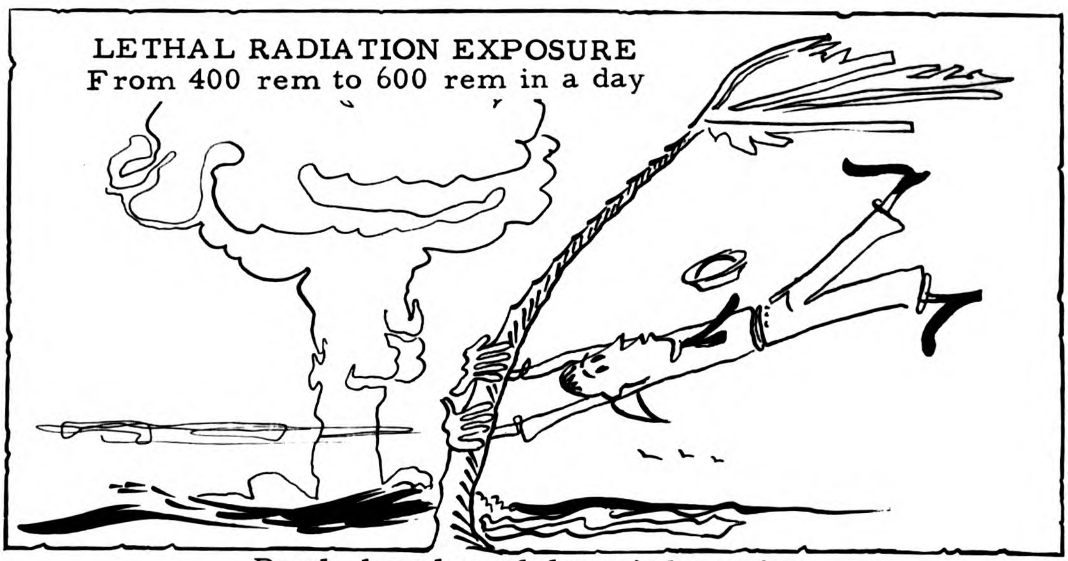
BACKGROUND RADIATION
0.0003 rem/day

Basking in the Cosmic Rays.

PERMISSIBLE RADIATION
0.050 rem/day



Braving the Radiations.



Dead already and doesn't know it.

BIOLOGICAL EFFECTS OF RADIATION

Ionizing radiation can injure human beings. Man is continuously exposed to radiation from naturally radioactive minerals in the earth and from cosmic radiation. There is even a small amount of radioactive matter in his body. To this natural radiation we are now adding radiation from machines, artifically produced radioactive materials, nuclear devices, and fission products from nuclear weapons. We must control the amount of radiation absorbed by man to limit harmful effects. This control can be accomplished by application of radiological safety (hereafter called rad-safe) procedures. THINK! PLAN! ACT!

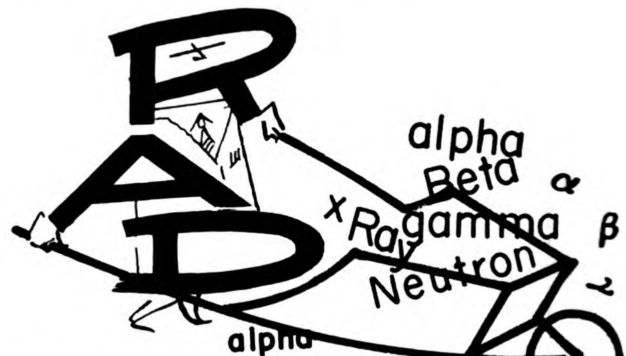
UNITS OF MEASUREMENT

Various units are used for measuring radiation, but the PHYSICAL MEASUREMENTS of radiation must be CONVERTED to BIOLOGICAL EFFECTS upon man.

R - RAD

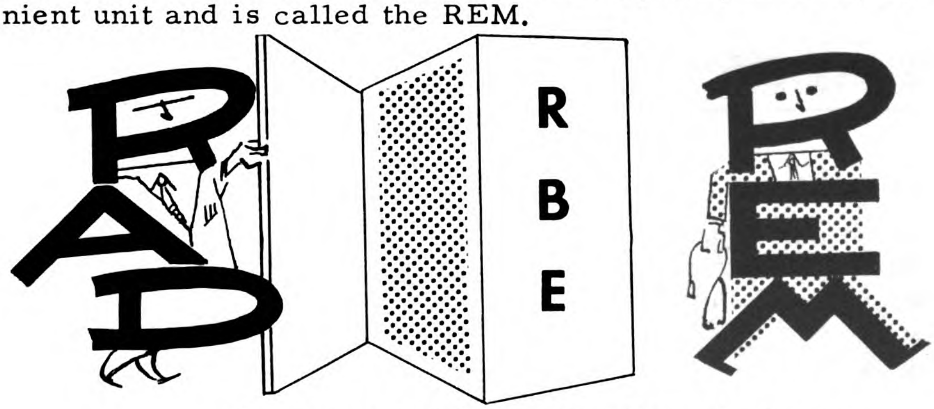
The ROENTGEN (r) is a unit of exposure that applies only to X rays and gamma rays. The absorbed dose in tissue is 93 ergs per gram from exposure to 1 r. This amount of absorbed dose used to be called 1 REP, but the term is now obsolete.

Since there are other types of radiation, such as alpha, beta, and neutrons, another unit of measurement must be defined. This new unit of absorbed dose is called the RAD. 1 RAD is the absorbed dose of 100 ergs per gram of any matter and can be used for any ionizing radiation.



REM - RBE

The RAD is a physical measurement, but the dose in rads does not tell us the biological effect. The physical dose, corrected by a factor for the relative biological effect (RBE) in man, is a convenient unit and is called the REM.



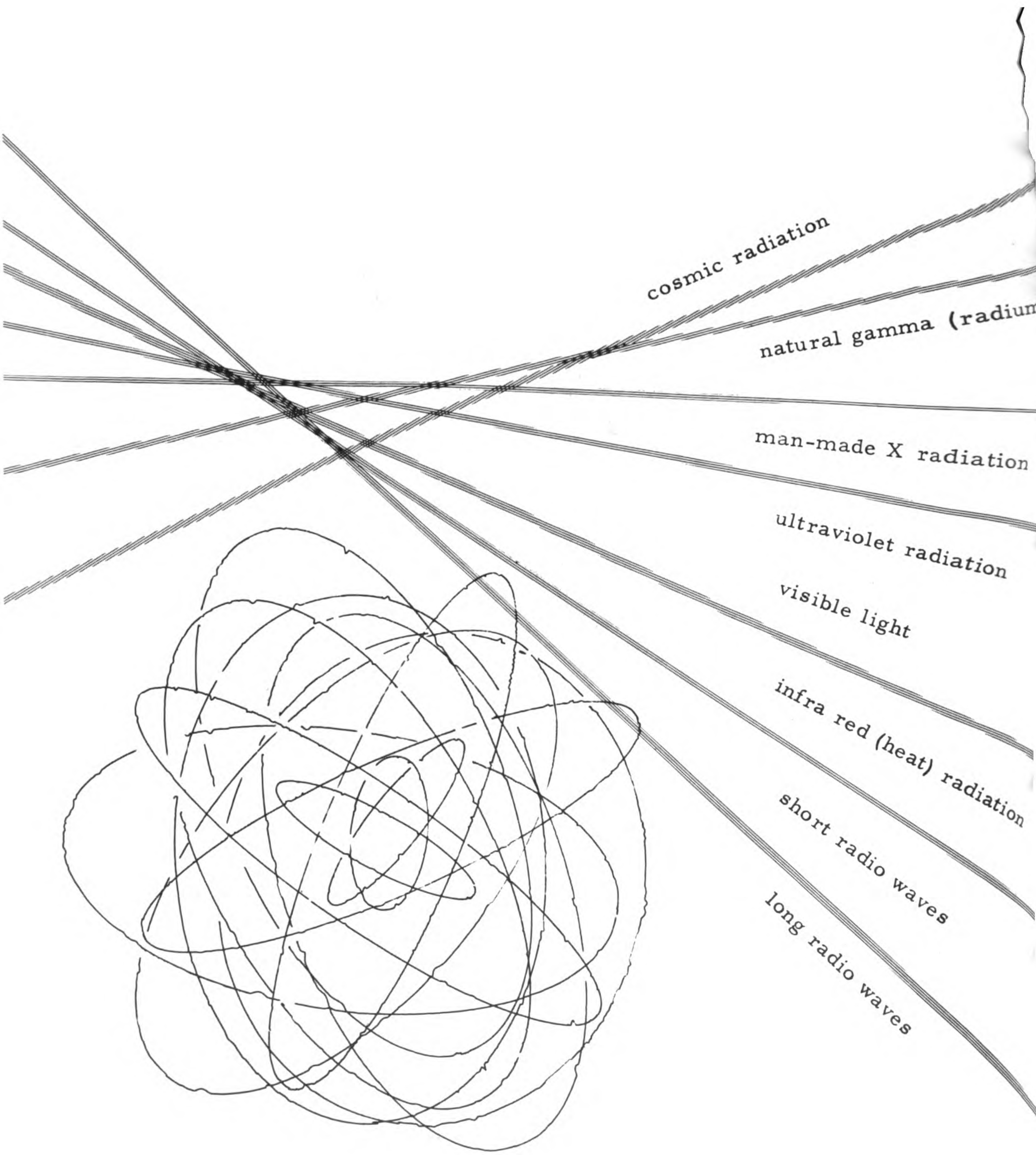
(Dose in Rads) x RBE = Dose in Rems

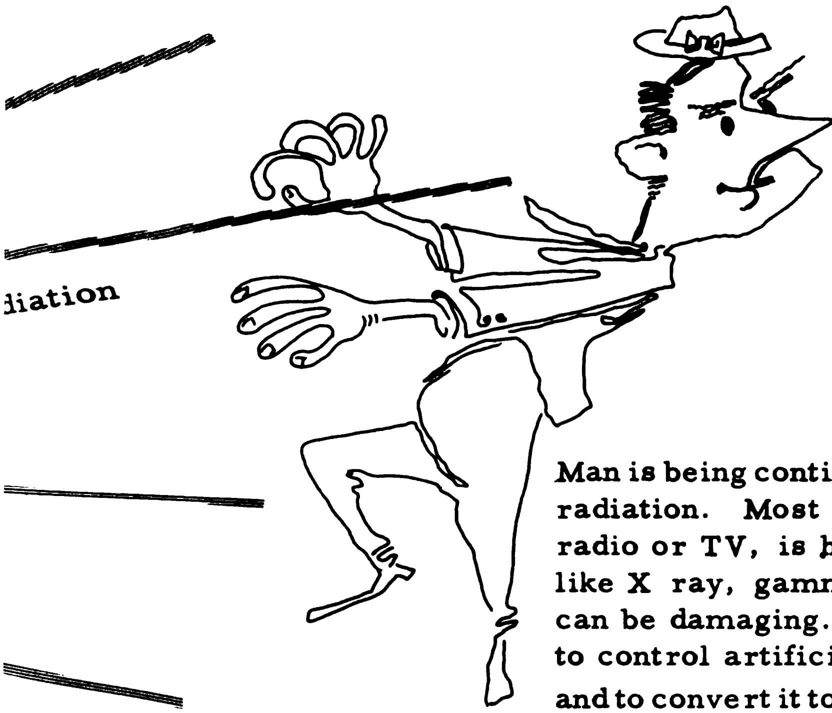
Careful study and research have established limits or safety factors for the amount of radiation that the human body should receive.

THE PERMISSIBLE DOSE OF RADIATION IS 0.3 REM/WEEK FROM EXTERNAL AND INTERNAL SOURCES TOGETHER.

The Maximum Permissible Exposure (MPE) of ionizing radiations and the Maximum Permissible Concentration (MPC) of radioactive isotopes are based on the premise that 0.3 REM PER WEEK will not produce any effects that anybody will become aware of.

If there is a chance of getting more than 0.05 rem in a week (1/6 of the MPE), the exposure must be kept track of. (See Film Badges, p. 29). Normally, the total dose during any one year should not exceed 5 rem. However, in certain cases, the yearly dose may total 12 rem provided that no more than 3 rem is received in any quarter. In any event, the individual's total lifetime maximum permissible dose (MPD) is limited to (N-18) x 5 rem, N being the individual's age. It is presumed that no one will start working where there is a radiation hazard before the age of 18.


cosmic radiation
natural gamma (radium)
man-made X radiation
ultraviolet radiation
visible light
infra red (heat) radiation
short radio waves
long radio waves



Man is being continuously bombarded by radiation. Most of this, such as light, radio or TV, is harmless. Much of it, like X ray, gamma or neutron radiation, can be damaging. It is possible, however, to control artificially produced radiation and to convert it to both peaceful, constructive use or to wartime destructive use.

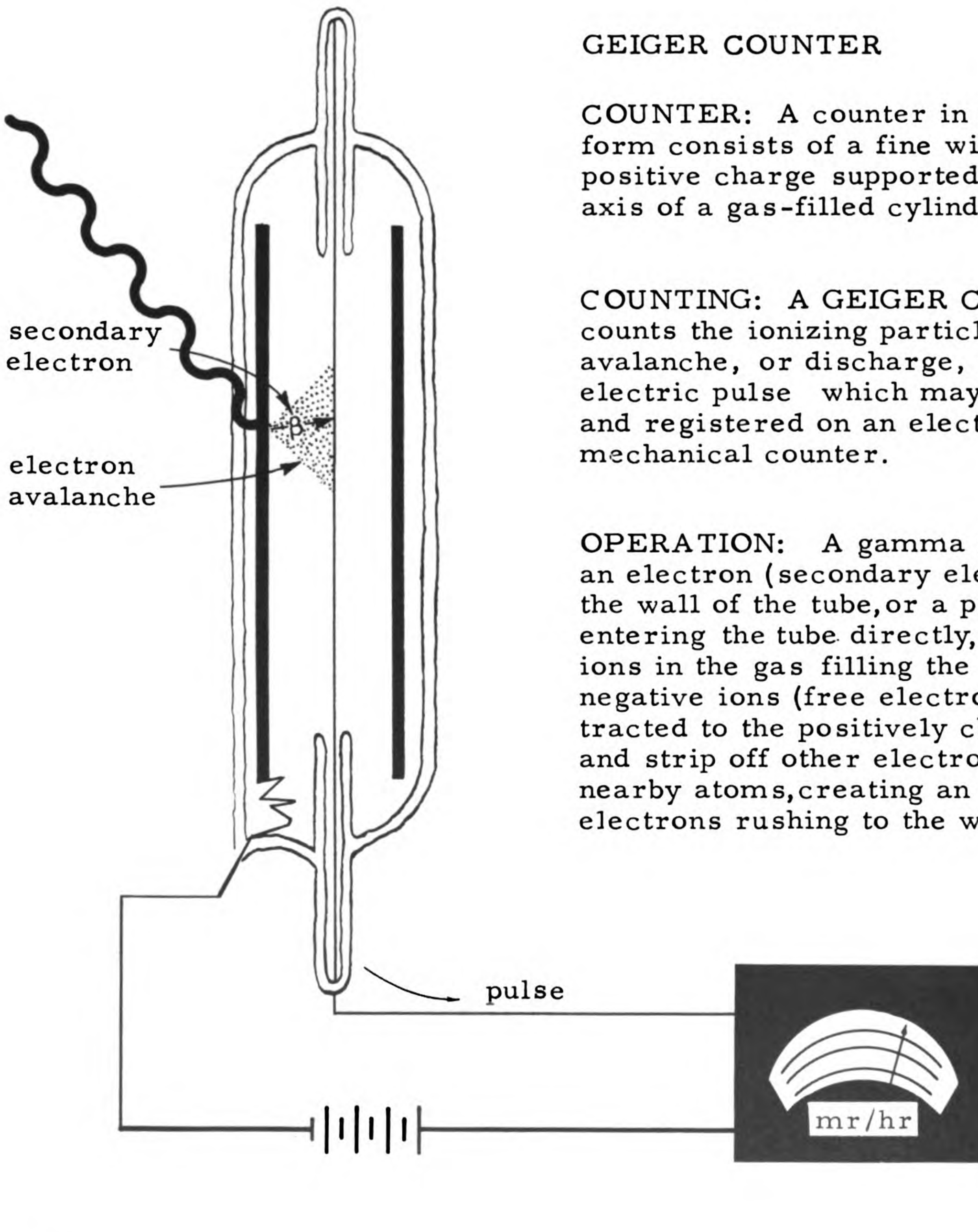
Radiation can be harmful, therefore it is imperative for man to know how to protect himself against excessive exposure to radiation.

JUST REMEMBER YOU CAN'T SEE 'EM
FEEL 'EM
HEAR 'EM
SMELL 'EM
TASTE 'EM

BUT... <u>You can detect them with radiation-measuring instruments</u>.

DETECTION AND MEASUREMENT OF RADIATION

The radiations that we are trying to guard against are all IONIZING RADIATIONS. This ionization is what makes radiation detection devices work. Some instruments count the number of ionizing particles and some measure the small amount of electricity that the ions carry.

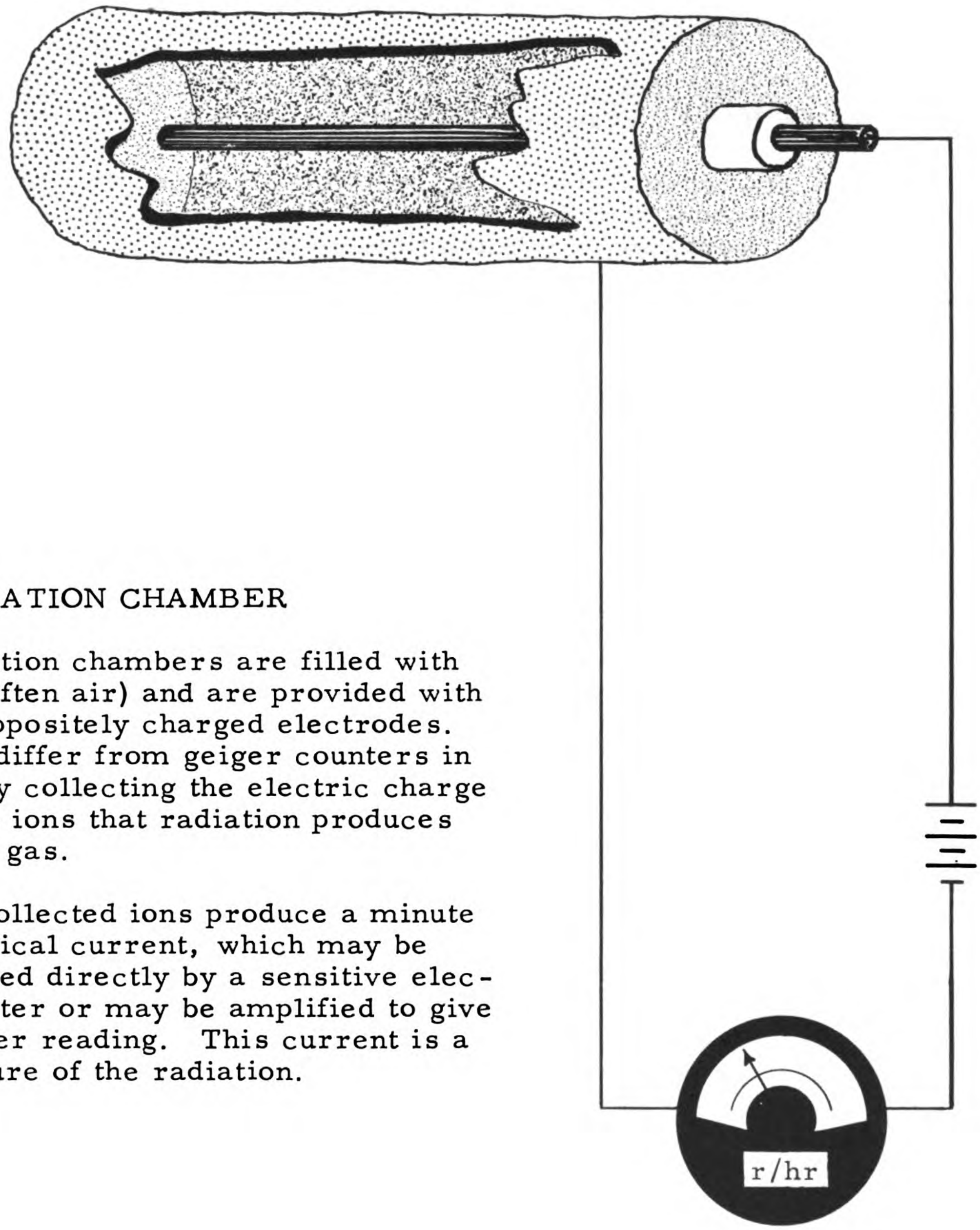


GEIGER COUNTER

COUNTER: A counter in its simplest form consists of a fine wire with a positive charge supported along the axis of a gas-filled cylinder.

COUNTING: A GEIGER COUNTER counts the ionizing particles. The avalanche, or discharge, produces an electric pulse which may be amplified and registered on an electronic or mechanical counter.

OPERATION: A gamma ray knocking an electron (secondary electron) from the wall of the tube, or a particle entering the tube directly, makes some ions in the gas filling the tube. The negative ions (free electrons) are attracted to the positively charged wire and strip off other electrons from nearby atoms, creating an avalanche of electrons rushing to the wire.



IONIZATION CHAMBER

Ionization chambers are filled with gas (often air) and are provided with two oppositely charged electrodes. They differ from geiger counters in simply collecting the electric charge on the ions that radiation produces in the gas.

The collected ions produce a minute electrical current, which may be detected directly by a sensitive electrometer or may be amplified to give a meter reading. This current is a measure of the radiation.

Radiation detection instruments are used to measure the various ionizing radiations for a multitude of scientific and engineering purposes. Particularly valuable are the radiation-detecting instruments called RADIACS which are used for monitoring and indicate whether or not any particular radiological situation is hazardous. RADIACS ARE THE TOOLS OF THE MONITOR.

DOSE AND DOSE RATE

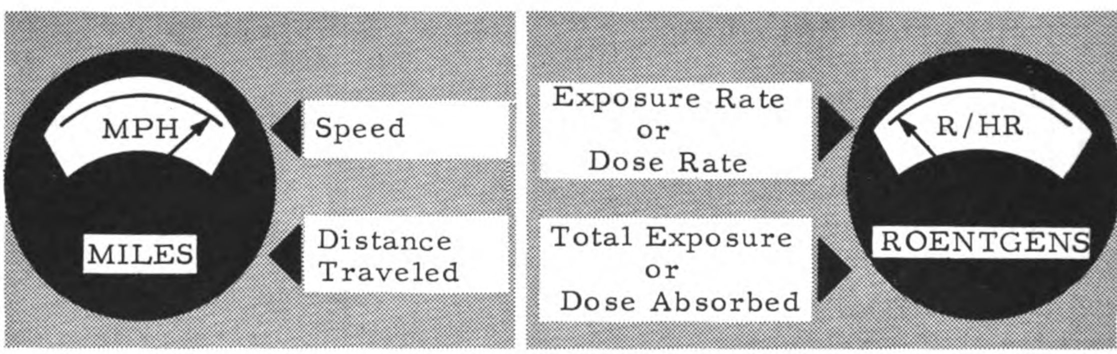
The two fundamental concepts in radiation monitoring are DOSE and DOSE RATE produced by ionizing radiation.

DOSE. The amount of ionizing radiation absorbed by a unit mass, i. e., the amount of radiation absorbed by every gram in the body when man works in a radiation field.

The dose for all types of radiation is measured in:

millirad (mrad) or rad - the PHYSICAL dose
millirem (mrem) or rem - the BIOLOGICAL dose.

When dealing with X or gamma rays, it is simpler to measure the EXPOSURE, i. e., the capability of producing an ABSORBED dose. In this case, the unit is the roentgen (r) or milliroentgen (mr).



DOSE RATE. The amount of ionizing radiation absorbed per unit time by a unit mass.

The dose rate is measured in:

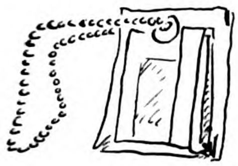
mrad/hr or rad/hr - the PHYSICAL dose rate
mrem/hr or rem/hr - the BIOLOGICAL dose rate.

EXPOSURE RATE is measured in mr/hr or r/hr.

INTENSITY, EXPOSURE RATE, AND DOSE RATE ALL MEASURE THE APPLICATION OF RADIATION. INTENSITY is the word used to mean the total radiation carried per square centimeter. EXPOSURE RATE measures the capability of the radiation to ionize. DOSE RATE measures its accomplishment in ionizing the material, of interest. Intensity includes the energy that passes on through, as well as the energy left behind in the form of ionization. Exposure rate and dose rate are only concerned with the energy left behind.

RADIAC INSTRUMENTS actually measure EXPOSURE and NOT the DOSE ABSORBED by the person. This ABSORBED DOSE is sufficiently predictable so that people often talk as though the instruments were measuring dose or dose rate.

For Measurement of DOSE, we have:

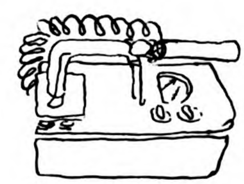


FILM BADGES - Ionizing radiation produces chemical changes - - darkening the film emulsion according to the amount of radiation absorbed. The dose indicated by the darkening depends upon the quality of the radiation.

POCKET IONIZATION CHAMBER - The ionizing radiation discharges the condenser in a pocket ionization chamber. The amount of discharge is a measure of the radiation dose.

PHOSPHATE GLASS DOSIMETER, DT-60/PD. Radiation causes changes in the special-formula glass which make it fluoresce with an orange light when later exposed to ultraviolet light. This brightness of this orange light is a measure of the dose.

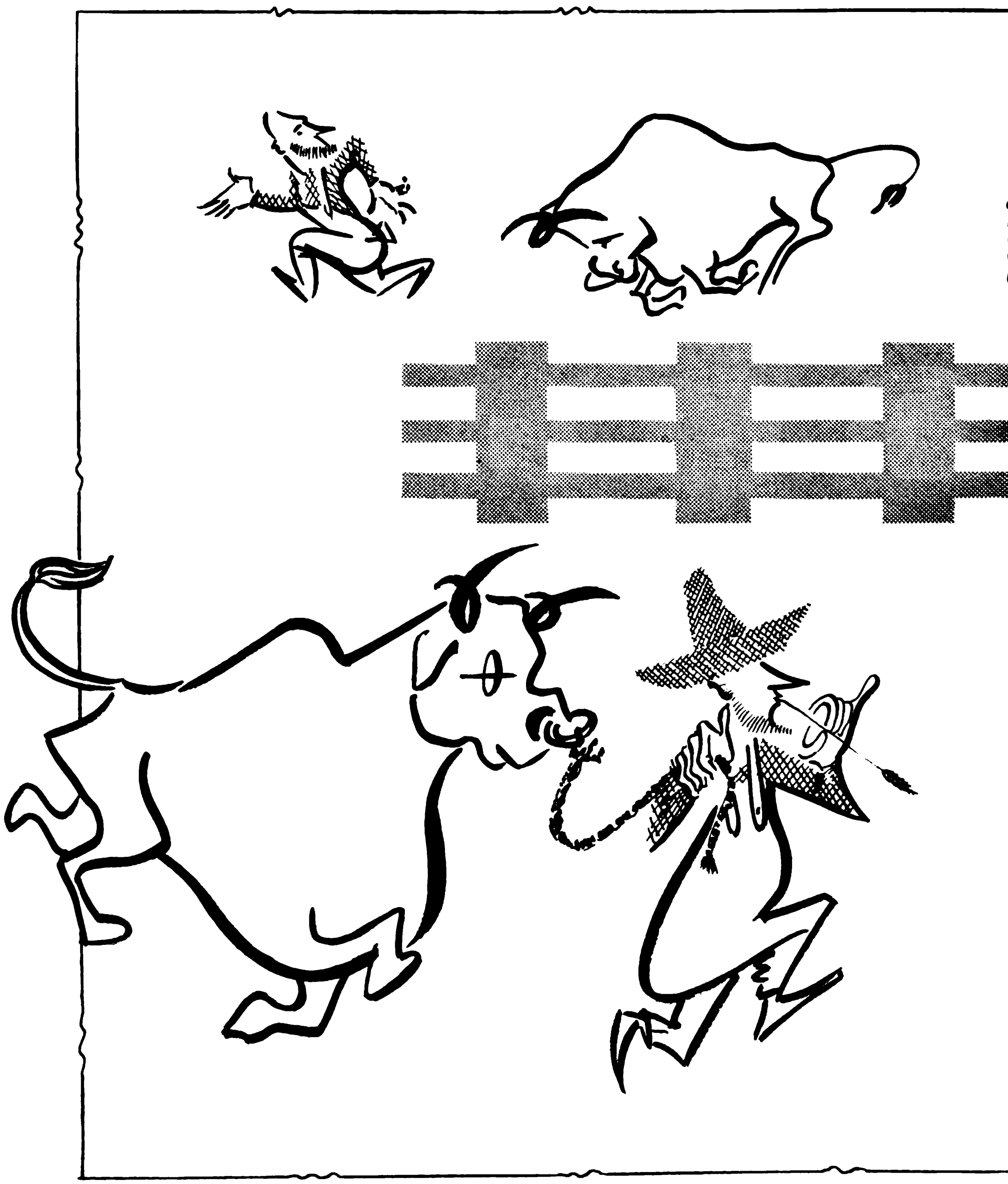
For Measurement of DOSE RATE, we have:



GEIGER COUNTERS - Ionizing radiation produces pulses in the GM tube. These pulses are amplified and fed into a count-rate meter.

ION CHAMBERS - Ionizing radiation produces a minute current which is fed to the meter through a high-resistance direct-current amplifier.

SCINTILLATION RADIACS - Ionizing radiation produces light flashes in certain crystals. These scintillations are picked up by a photomultiplier tube. The current or pulse rate is fed into a count-rate meter.



RADIOLOGICAL SAFETY - the techniques for safe work in and around radiation zones and contaminated areas.

Ionizing radiations produced by radioactive materials or machines are now part of everyday technology and of everyday living.

Radiation can be dangerous if used improperly. For proper use, radiological safety procedures must be followed.

Familiarity with the chemical and physical properties of radioactive materials and ionizing radiations is basic to determining the proper safety measures to be employed.

RADIOLOGICAL SAFETY IS NOT AN END IN ITSELF; IT IS A METHOD OF SAFELY ACCOMPLISHING WORK IN OR AROUND CONTAMINATED AREAS AND RADIATION ZONES. Prime necessities for radiological safety are TRAINING and extensive PLANNING. Common sense and experience should dictate the radiological safety procedures called for in any situation involving radiation.

Radiological safety must be an integral part of all phases of any operation, whether it be the experimental laboratory, the production facility, the nuclear reactor, the weapon test, or nuclear warfare.

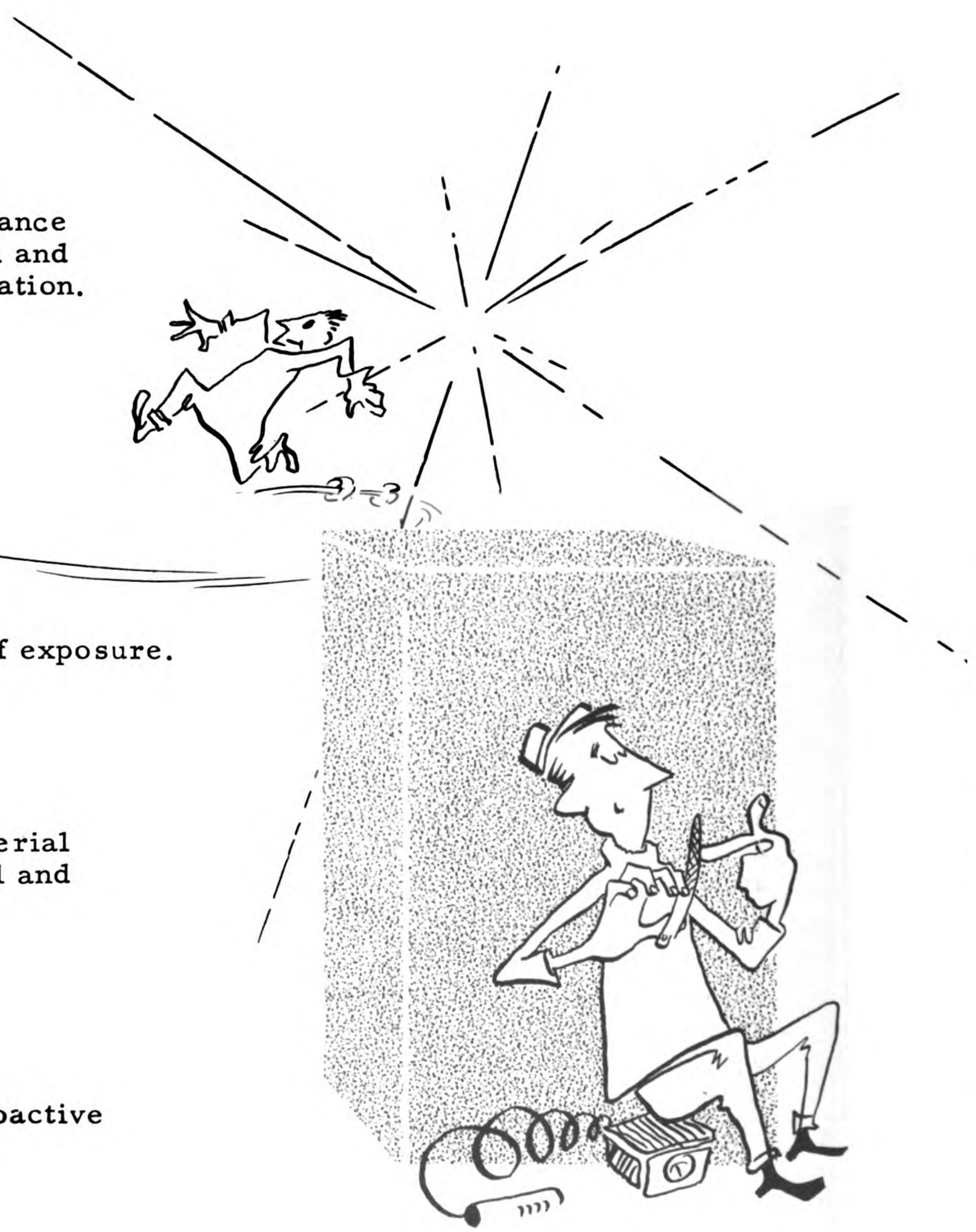
Emphasis must again be placed on the fact that radioactive materials and ionizing radiations are dangerous if used improperly. Study of the chemical and physical properties of radioactive materials and knowledge of their ionizing radiations, when added to common sense and experience in handling, will dictate the radiological safety procedures necessary.

Planning the safety program involves not only personnel actively engaged in the immediate operation, but also involves those who will inhabit the area in the future. Thus, radiological safety must always be emphasized, for many of its aspects will extend far beyond the scope of the immediate operation.

THE TWO BASIC CATEGORIES OF PERSONNEL DOSAGE CONTROL ARE:

EXTERNAL RADIATION DOSAGE CONTROL

When the source of ionizing radiation is located outside the body, the important factors in controlling dosage are DISTANCE, TIME, SHIELDING, and DECAY.



Maximize the distance between personnel and the source of radiation.

Control the time of exposure.

Put shielding material between personnel and the source.

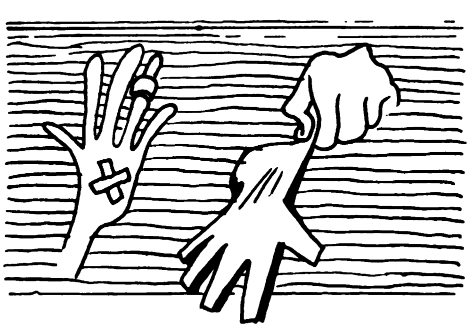
Wait for the radioactive source to decay.

When the source of ionizing radiation is located inside the body, the best you can do is to try and get it out again. This is usually not very successful. The best PROTECTION is not to let it get inside in the first place.

The factors of distance, time and shielding have a slightly different application in internal dosage control. When working in a contaminated area, man must always protect himself from INHALATION, INGESTION, and ABSORPTION of radioactive material.

Hold your breath and get out, or wear a gas mask, when radioactive material gets loose.

Don't Eat. Don't Drink. Don't Smoke. Don't Primp --- where radioactive material is unconfined.



Wear gloves and cover cuts when handling radioactive material or contaminated equipment.

DOSE AND DOSE RATE ESTIMATES

The following guidelines show the relationship between the amount of radioactive material, the resulting exposure dose rate, and stay time.

STAY TIME

$$\text{STAY TIME} = \frac{\text{ACCEPTABLE DOSE}}{\text{DOSE RATE}}$$

EXPOSURE DOSE RATE from a POINT SOURCE

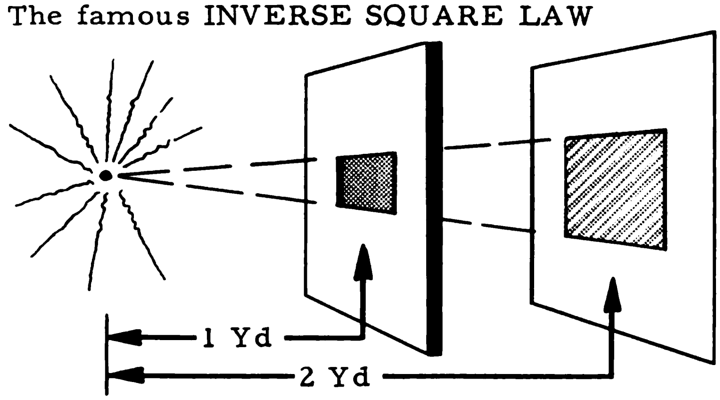
It just happens that hard gamma rays coming from 1 curie of a radioactive isotope give about

6 r/hr at 1 foot

The practical formula is: $D_1 = 6CE$

where, D_1 is the dose rate at 1 ft from the source.

The famous INVERSE SQUARE LAW



twice as far,
1/4 the dose rate

3 times as far,
1/9 the dose rate

10 times as far,
1/100 the dose rate

$$D_r = \frac{1}{r^2} \times D_1$$

Put it all together:

$$D_r = \frac{1}{r^2} \times C \times E \times 6 \text{ r/hr}$$

D_r is the dose rate in r/hr at a distance from a point source

r^2 is the square of the distance from the source (in feet!!)

C is the curie strength of the source (the curie is that amount of radioactive material that disintegrates at a rate of 3.7×10^{10} d/sec)

E is the energy of the gamma radiation in Mev (million electron volts).

RULES OF THUMB

The following simple rules are used to estimate radiation dose and dose rates from fisson products of a bomb.

Double the time since detonation, dose rate is down to 1/2. Say it another way: the apparent half-life is about equal to the age.

At seven times the present age, the radiation level will be 1/10 the present dose rate. From age 1 day to age 7 days, the dose rate falls to 1/10; at age 49 days it falls to 1/100.

For short time exposure (less than one apparent half-life), assume dose rate constant.

Gamma dose to infinite time equals 5 x r/hr at present x hours since detonation...or 5IT.

Dose accumulated in one apparent half-life equals one-tenth of 5IT.

WORK WITHIN THE WEEKLY MPE AND MPC

0.3 rem/wk of ionizing radiation does not produce any effect that a person will become aware of. This 0.3 rem/wk is the maximum permissible limit (MPL) of the SUM OF EXTERNAL RADIATION EXPOSURE AND INTERNAL BODY CONTAMINATION.

EXAMPLE:

External Exposure	0.2 rem
Internal Body Contamination	0.1 rem
Total Dose	0.3 rem

WORK WITHIN THE LIFETIME MAXIMUM PERMISSIBLE DOSE (MPD)

It is imperative to observe the lifetime permissible dose. Even though a person steps over the 0.3 rem/wk sometimes, the total accumulation (MPL) in any calendar year shall not exceed 12 rem, with the further limitation that the person's total lifetime dose (MPD) must not exceed (N-18) x 5 rem. (N is the individual's age, and greater than 18.)

Maximum Permissible Dose (MPD) equals (N-18) x 5 rem

DOSAGE BANK BOOK OF John Doe AGE 24 IN 1954

DOSE PREVIOUS TO 1954 IS 3 rem	DOSE IN REMS 1954	1955	1956	1957
MPD	30	35	40	45
Total Accumulated Dose	3	11	22	31
Reserve (MPD-Acc. Dose)	27	24	18	14
Yearly Dose →	8	11	9	

RADIOLOGICAL SAFETY WORK PRACTICES TO BE OBSERVED

1. **KEEP CLEAN AND NEAT:** Practice good housekeeping and good personal hygiene.
2. **MINIMIZE EXPOSURE:** Be sure of personal dosage record--keep an up-to-date account.
3. **WEAR PERSONNEL DOSIMETERS:** Remember, man can't feel, see or hear radiation--but the dosimeter can.

WHEN WORKING IN A RADIATION ZONE:

1. Plan the job in advance. Do a dry run.
2. Monitor the job area; measure the radiation level.
3. Define the area which is prohibited to unauthorized personnel.
4. Control exposure time. If exposures approach MPL, rotate personnel.

WHEN WORKING IN A CONTAMINATED ZONE:

1. Plan the job in advance.
2. Monitor the airborne contamination.
3. Measure the radiation intensity and set up zone control.
4. Prohibit the contamination area to unauthorized personnel.
5. Allow no eating, smoking or drinking in the contaminated area except under controlled conditions.
6. Wear adequate protective clothing.
7. Control the further spread of the contamination.

THE RADIOLOGICAL SAFETY MONITOR MUST ALWAYS KNOW:

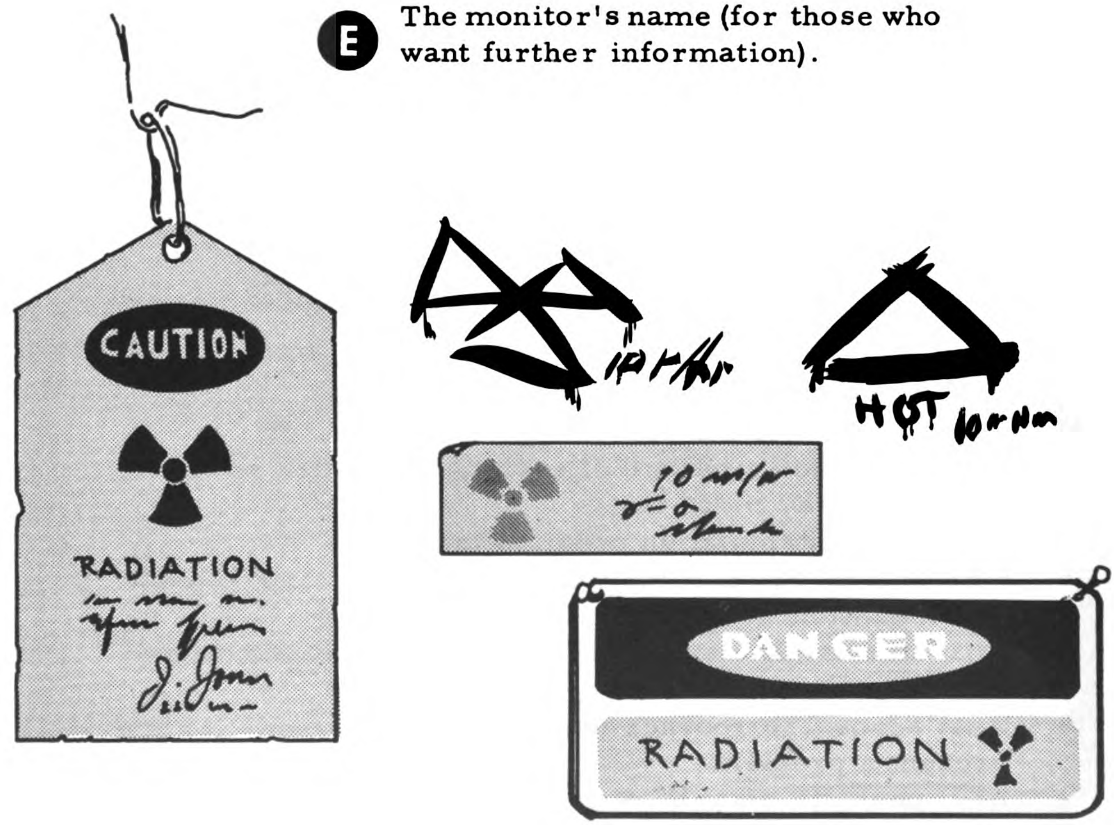
1. What types of radiation are present.
2. What the intensity of the radiation is.
3. What the relative hazard of each type of radiation is.
4. What the "stay time" is.
5. What the contamination problem is.
6. What internal contamination problem the removable contamination will create.
7. What industrial nuisance the removable contamination will create.
8. What aerosol (airborne) contamination may exist or present a problem.
9. What controls must be dictated to protect personnel.

MARKING RADIATION ZONES AND CONTAMINATED EQUIPMENT

Put up signs to mark radiation and contaminated areas and tag contaminated equipment with the standard radiation symbol to warn other personnel of the hazard.

Signs and tags should indicate as appropriate:

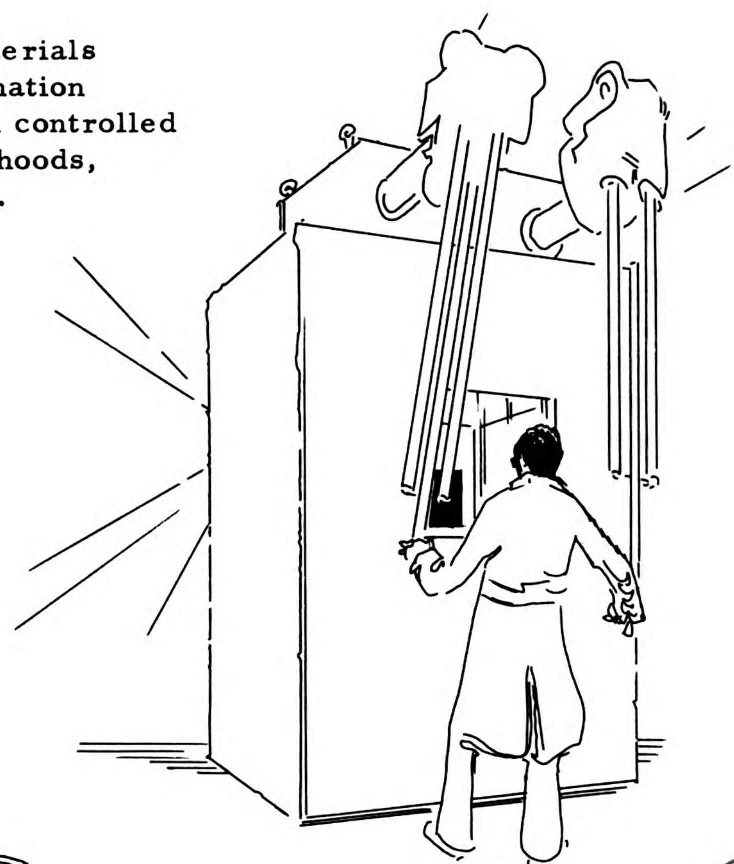
- **A** The type of radiological hazard. (radiation or contamination).
- **B** The intensity of radiation and stay time.
- **C** The amount of removable contamination.
- **D** The protective equipment required.
- **E** The monitor's name (for those who want further information).

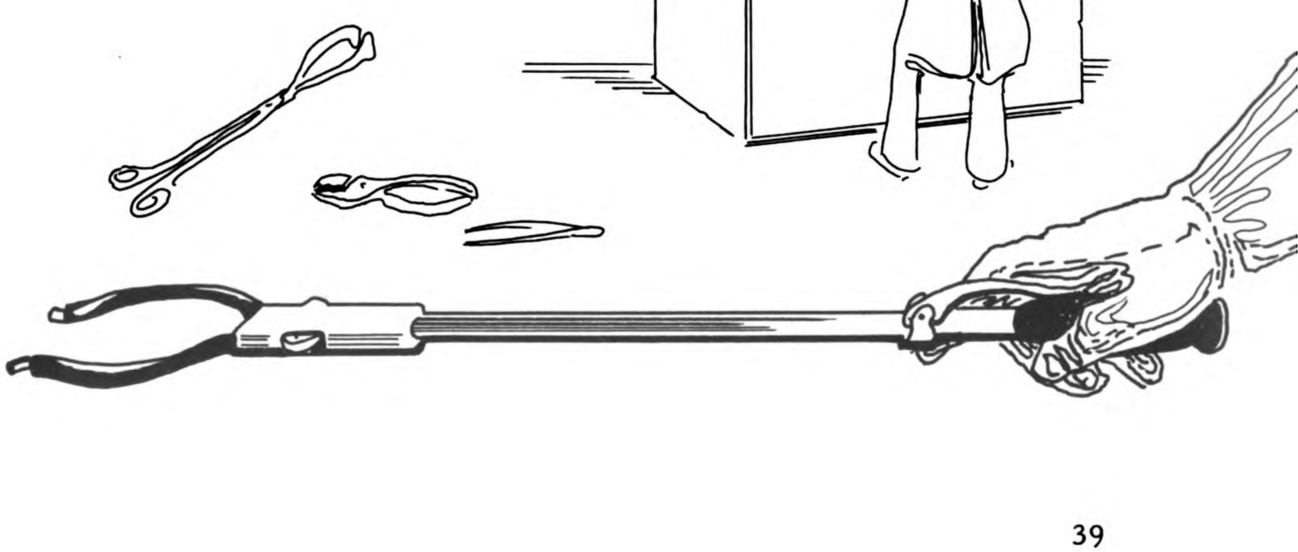


Never handle radioactive material with bare hands. There are a variety of handling tools: tweezers, pliers, strings, tongs, pick-up tools, etc., that can be used.
Choose the tool that will do the job, keeping the maximum distance from the source when external exposure is a factor.

Use shielding wherever possible to minimize body dosage. Practice will enable one to do any job behind shielding.

Work on radioactive materials which may be a contamination hazard should be done in controlled atmospheres such as in hoods, "dry boxes" or hot cells.



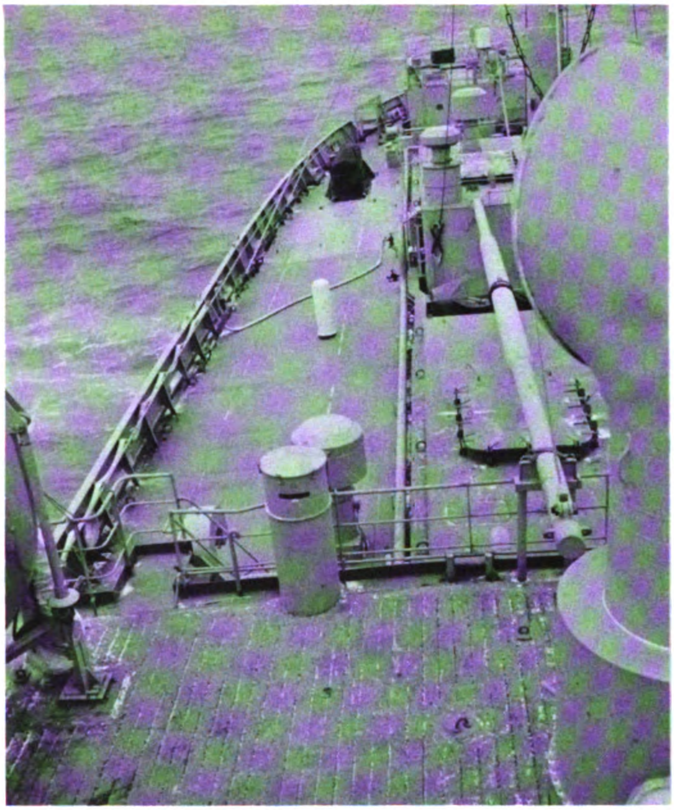


RADIATION VERSUS CONTAMINATION

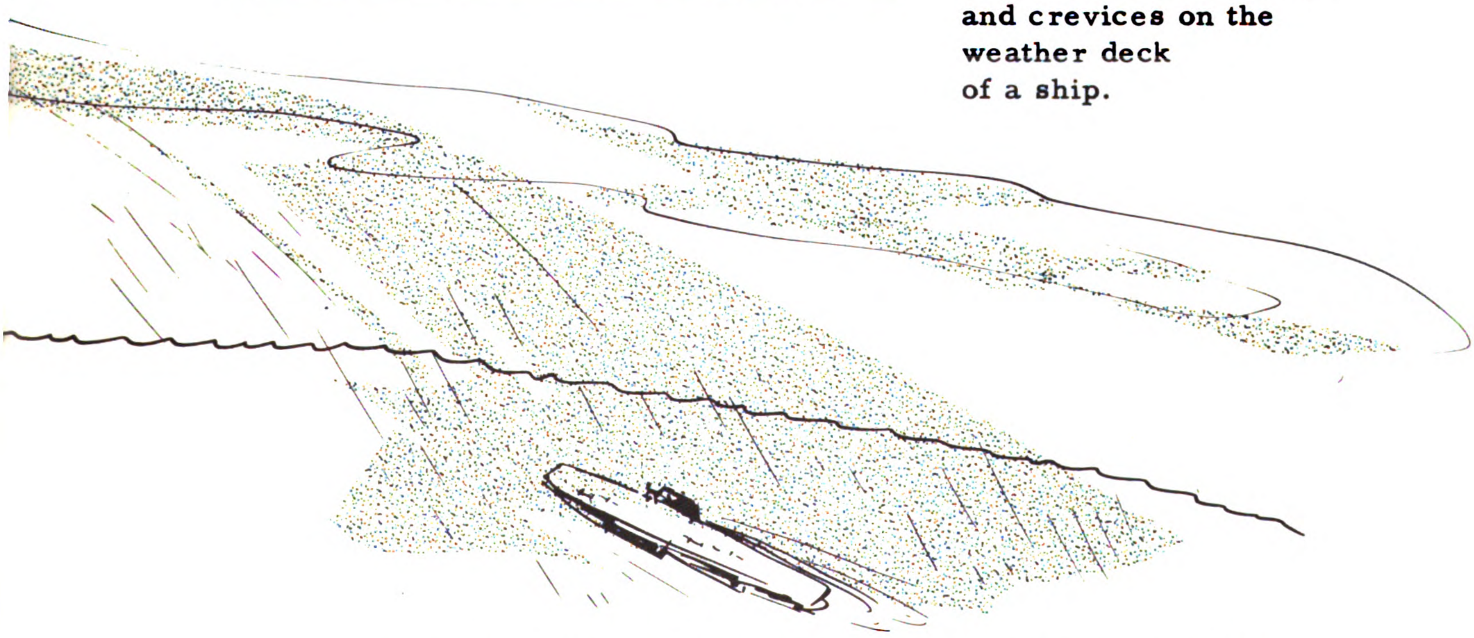
The term RADIATION will be used henceforth to mean those ionizing radiations emitted by radioactive materials or produced by machines.

The term CONTAMINATION will be used to mean radioactive material which has been deposited in an undesired location. Radioactive contamination is material that "dirties" an object or area. All radioactive contamination emits ionizing radiations, but material emitting radiations is not necessarily contamination.

Radiation only from fallout cloud passing over.

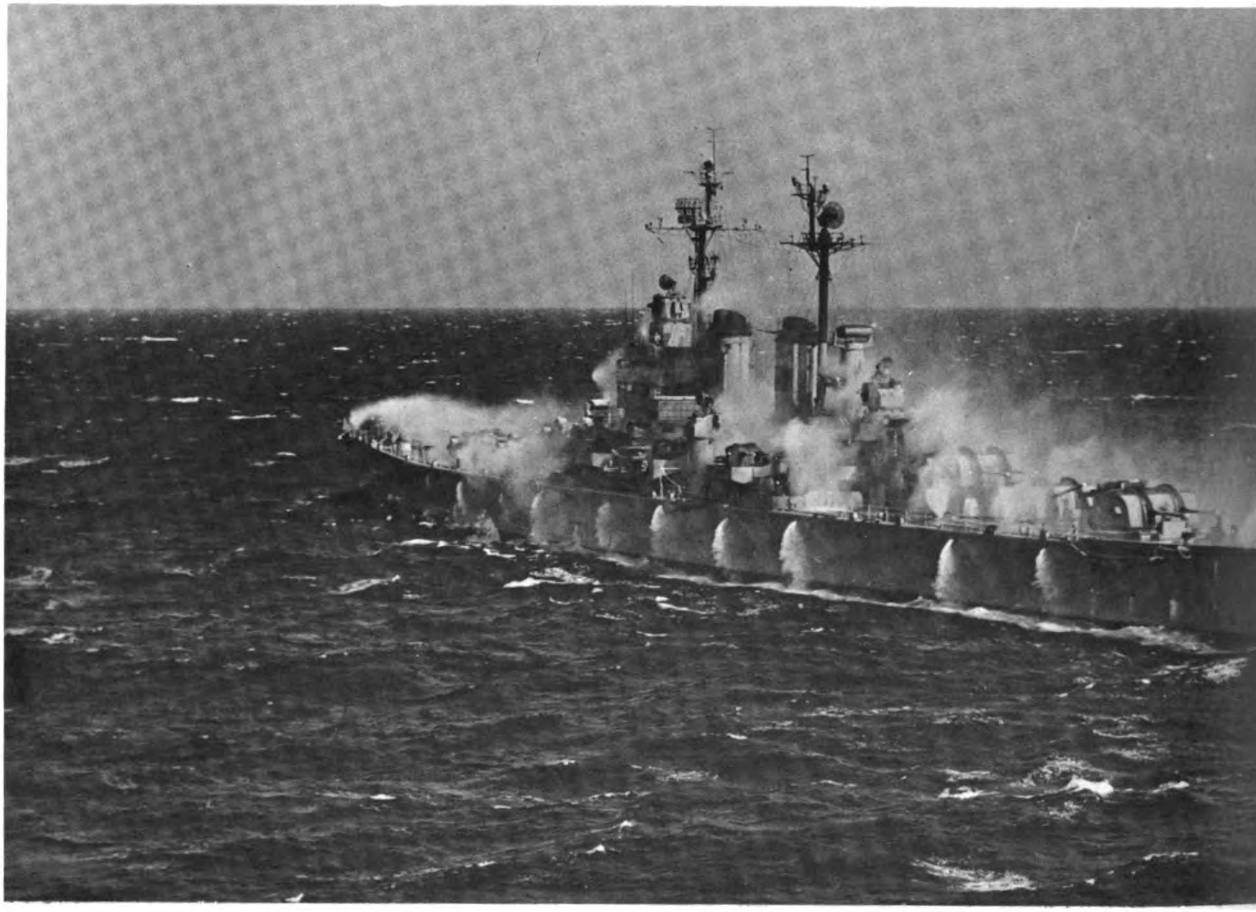


Radioactive fallout collected in the cracks and crevices on the weather deck of a ship.

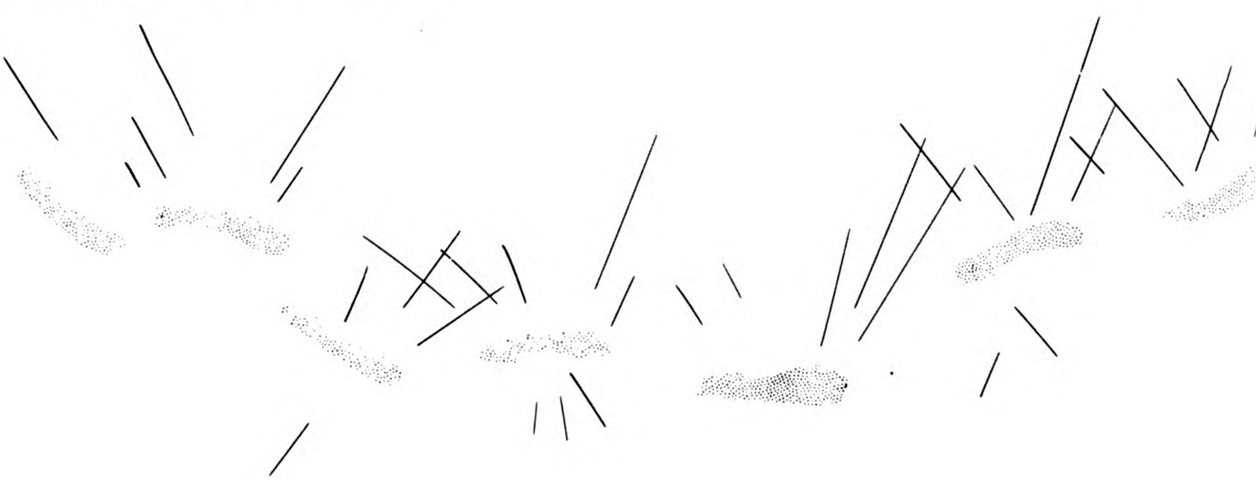


Radiation and contamination from cloud fallout on a ship.

SHIP WASHDOWN



Ship washdown in operation to prevent fallout contamination from adhering to weather surfaces.

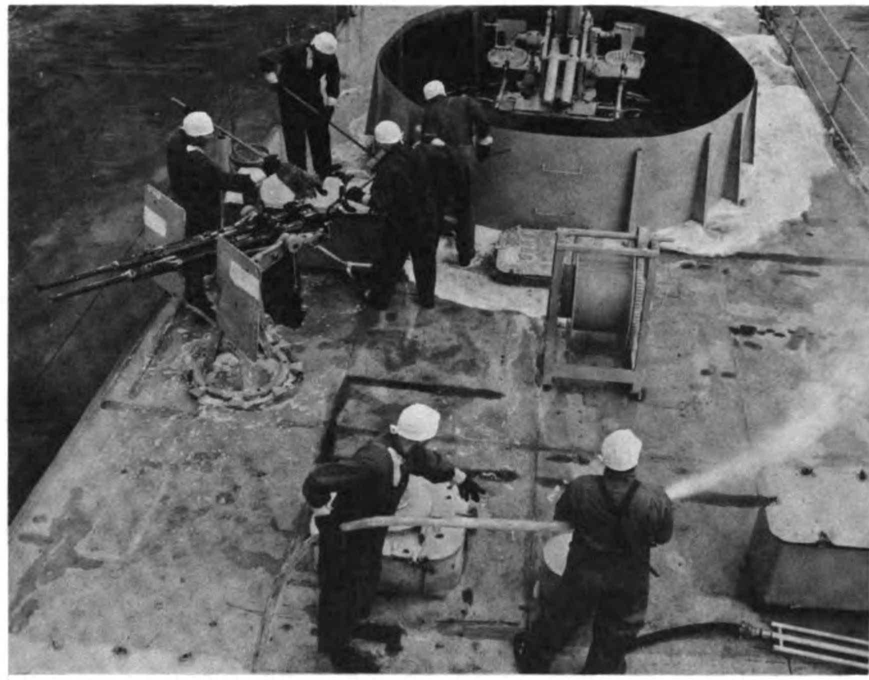


ZONE CONTROL OF CONTAMINATION

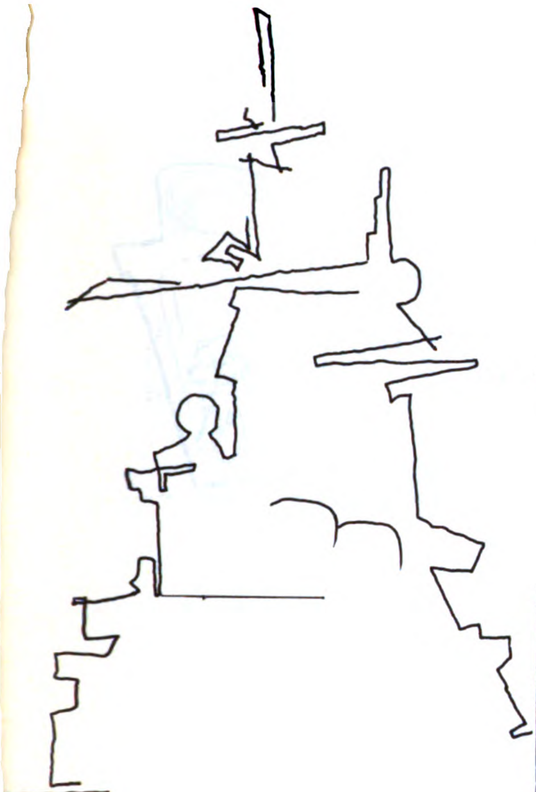
Limits of the contamination zone must always be clearly indicated so that no question exists concerning the boundaries between the contamination and the clean zone. The flow of personnel and equipment in and out of the contamination zone must be controlled to prevent spreading the contamination.

A ship presents a unique problem of contamination control. On board ship all interior spaces should be kept as clean as possible.

DECONTAMINATION

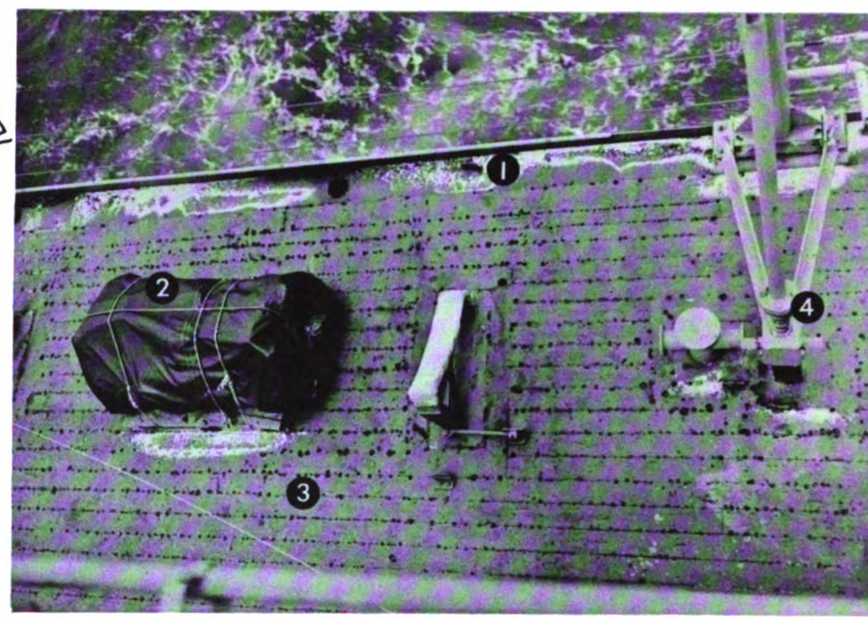


Decontamination is the process of removing radioactive contamination from an undesirable location to another location where the contamination is acceptable. **DECONTAMINATION DOES NOT DESTROY THE RADIOACTIVITY.** The radiological hazard is controlled by concentrating and confining the radioactive material as is done in industrial operations, or by diluting and dispersing the radioactive material as in field situations.



Radioactive materials contaminate by

1) lying loosely on the surface; subject to movement, tracking by shoes, etc.,
2) being absorbed in porous material such as rope or cloth,
3) being "adsorbed" to the surface in the form of ions, atoms, or molecules,
4) becoming mechanically bonded to surfaces through oil or grease films.

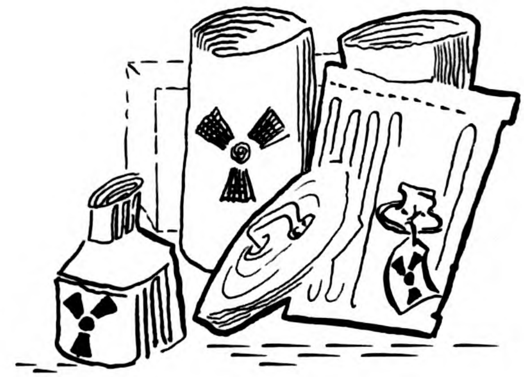


Cleaning equipment (firehoses, brushes, detergents) are good decontamination tools if properly used. Always remember to remove contamination to a location where it can be controlled, ultimately disposed of, or immobilized. Always choose a decontamination technique that will not destroy the utility of the object being decontaminated. COMMON SENSE IS THE KEYNOTE IN DECONTAMINATION.

Radioactivity does not alter the chemical properties of the radioactive material. Cleaning procedures that are satisfactory for ordinary industrial dirt are the same ones to be chosen when the contamination is in the same kind of dirt.

RADIOACTIVE WASTE DISPOSAL

In laboratory and industrial applications, radioactive waste must be CONFINED and CONTROLLED for disposal according to present laws. In nuclear weapon tests, radioactive material is DILUTED and DISPERSED over large UNINHABITED land or ocean areas.



PROTECTIVE CLOTHING

a necessity in the control of radioactive contamination

Full body covering for hosing operation

Control of radioactive contamination requires the use of protective clothing so that body contact with contamination is minimized. Use of protective clothing also limits the spreading of contamination to clean areas. Radiological safety protective clothing provides partial or full coverage of the body by a fine weave cloth, plastic, or rubberized material. Thus contamination is prevented from coming in contact with the body. Protective clothing should be simple to put on and take off in a short time with a minimum of contamination transfer.

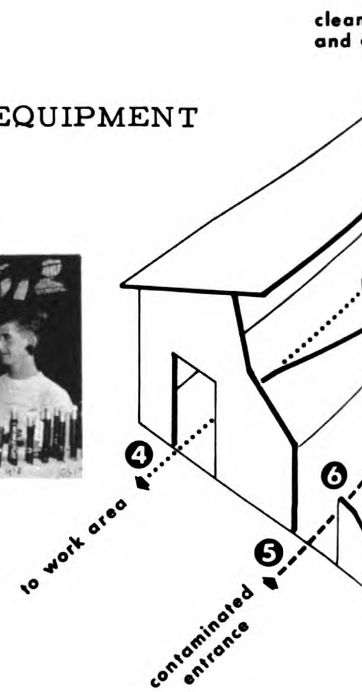
Partial dress out for scrubbing operations

Common sense dictates the use of protective clothing. The DEGREE OF DRESS OUT SHOULD BE COMPATIBLE WITH THE CONTAMINATION POTENTIAL. When walking through a contamination area, shoe protection may be the only requirement, whereas working in a highly contaminated area may require full dress out. Respiratory protection is determined by the actual and potential airborne contamination hazard.

An example of full dress out

PERSONNEL DECONTAMINATION

A basic technique in minimizing personnel contamination is the use of a PERSONNEL DECONTAMINATION CENTER (DECON CENTER). The CENTER is set up at the borderline between the clean and the contaminated zones. All personnel are briefed, then equipped with protective clothing and dosimeters before entering any contaminated zone. They return to the DECON CENTER for monitoring and decontamination before re-entering the clean zone. Equipment decontamination centers are set up in a similar manner to prevent the spread of contamination to clean areas.



1

PROTECTIVE CLOTHING AND EQUIPMENT STORAGE AND ISSUE

2

DOSIMETER ISSUE

3

CHANGE FROM PERSONAL APPAREL TO PROTECTIVE CLOTHING

4

DEPARTURE TO WORK AREA

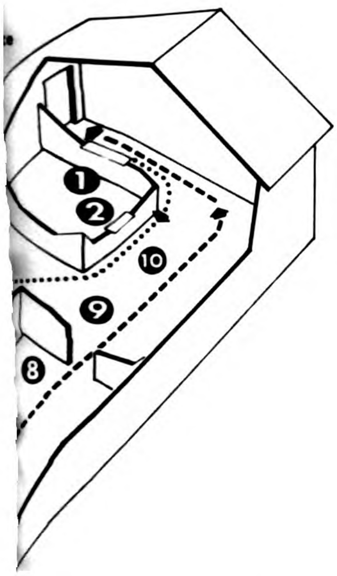
5

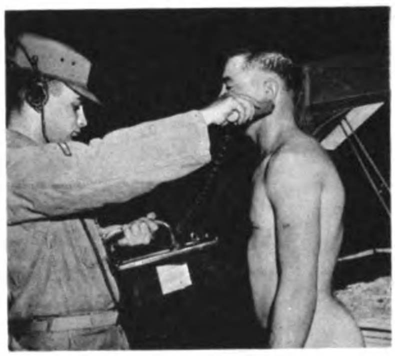
INITIAL MONITORING TO SEGREGATE HIGHLY CONTAMINATED PERSONNEL

CENTER

10

DRESSING IN PERSONAL CLOTHING





9

MONITORING CHECK

8

DECONTAMINATION

MONITORING TO LOCATE "HOT SPOTS"
(H marks the "hot" spots)

7

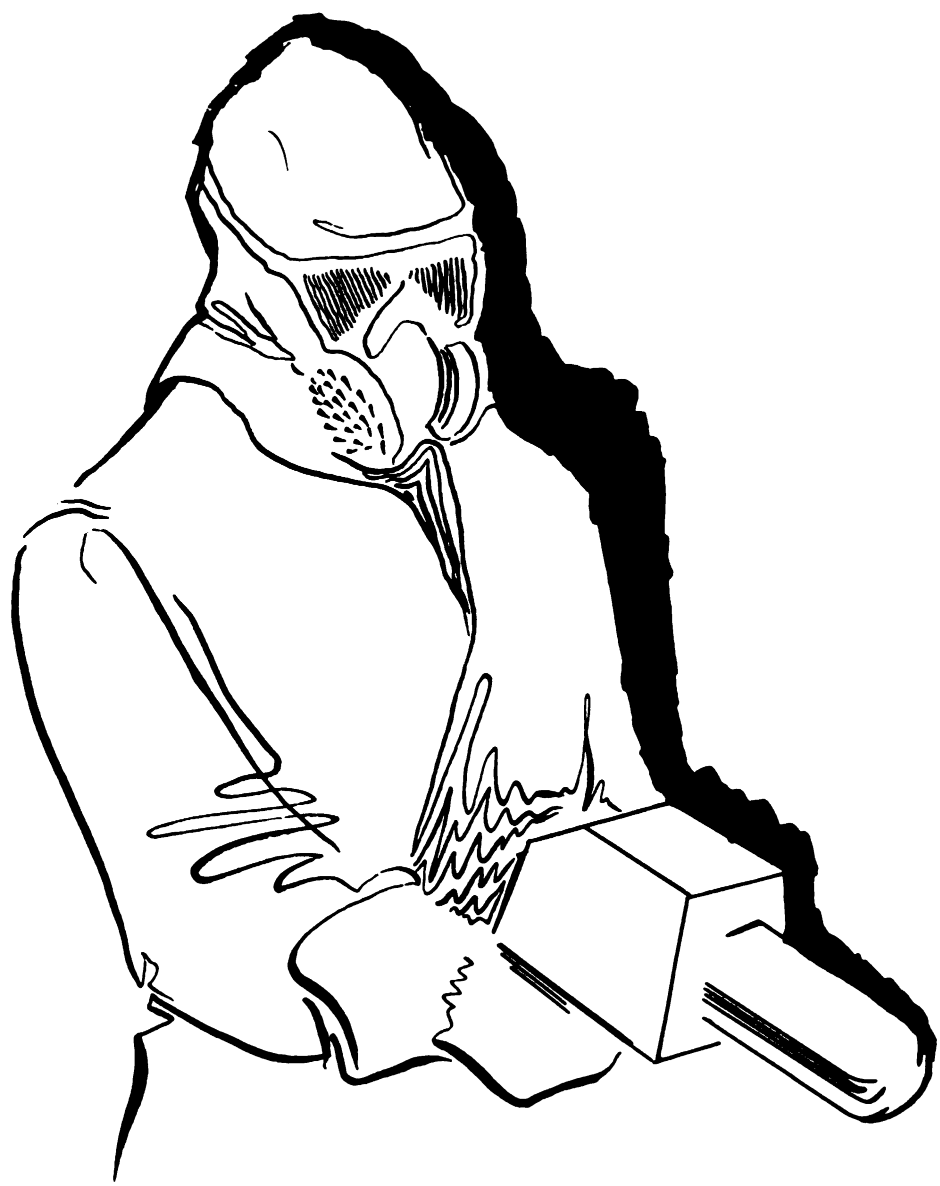
USE COMMON SENSE. Remember that contamination is the same as dirt except the dirt contains some radioactive material. Procedures that remove the dirt will also remove the contamination.

6

REMOVAL OF CONTAMINATED PROTECTIVE CLOTHING

RADIATION MONITORING

a necessary function in the assessment of any radiological situation



Radiation monitoring is a systematic method for determining the nature, the extent, and the magnitude of radiation and contamination hazards, using RADIACS, the tools of the MONITOR.

RADIATION MONITORING REQUIRES THE MONITOR TO KNOW

- The types of radiation and/or contamination.
- The radiation exposure rate and the amount of contamination (fixed or removable).
- The form and concentration of the radioactive material -- solid, liquid or aerosol.

The monitor must assess the radiological situation in order to establish what is necessary for decontamination and dosage control. This control is accomplished by:

- Limitation of stay-time in the radiation area. Occasionally putting up shields or using remote handling devices.
- Removing the contamination or immobilizing it. Using protective clothing and, if necessary, controlled atmospheres.

THE MONITOR MUST ALWAYS RECORD

1. The object or area monitored
2. Its exact location (with reference to some fixed point)
3. The types and intensities of radiation and/or contamination
4. The distance of the radiac from the object and area monitored
5. The time and date of measurement
6. The identification of the monitor.

MONITORING EQUIPMENT

RADIACS (Radiation Detection Instruments)

γ RADIACS	$\beta\gamma$ RADIACS	α RADIACS	AEROSOL SAMPLER
AN/PDR-27	Eberline E112B	AN/PDR-10	"Staplex" or other Spot air sampler
AN/PDR-18	Cutie Pie	Eberline PAC-3G	

DOSIMETERS - Film badges, pocket ionization chambers (self-indicating).
RECORDS - Monitoring forms, maps or charts.
WALKIE-TALKIE - Or other communication equipment.
MARKERS - Radiation signs or tags; grease pencil or chalk.
ACCESSORIES - Protective clothing, watch, transportation.

The GROSS MONITORING SURVEY is made to give an "order of magnitude" estimate of the radiological situation and the DETAILED MONITORING SURVEY is made to evaluate the "complete" radiological situation.

BASIC MEASUREMENT TECHNIQUE

Monitoring survey measurements must be standardized to permit proper evaluation of the radiological situation. The three basic monitoring techniques are:

<u>The Waist-High Measurement</u>
to evaluate the general or average gamma radiation intensity.

<u>The Near Contact Measurement</u>
to evaluate the surface gamma and/or beta radiation intensity. Alpha monitoring must be done by near-contact measurements.

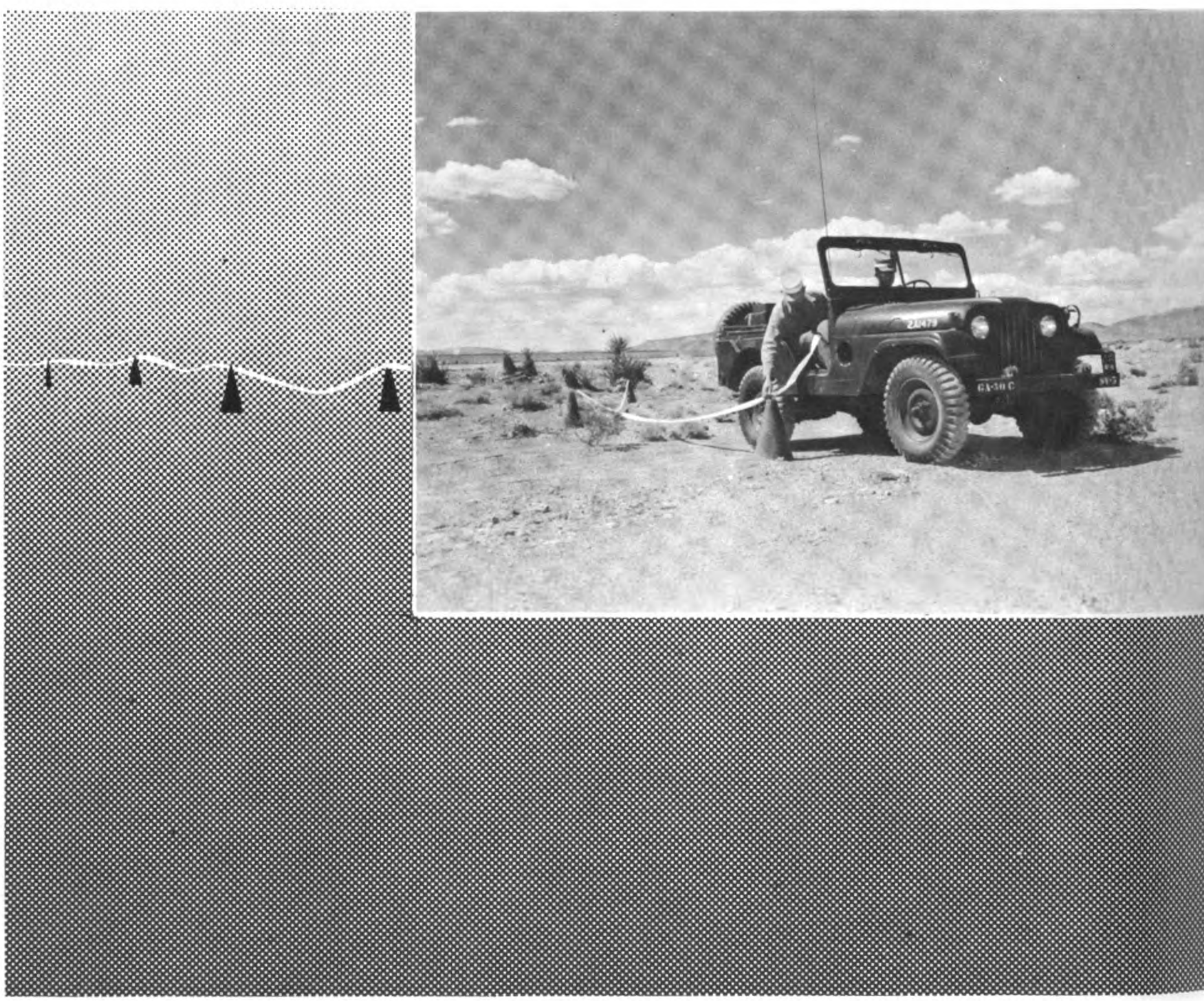
<u>Wipe Survey</u>
to evaluate the amount of removable contamination.

RAPID OR GROSS MONITORING SURVEYS

Rapid or Gross Monitoring Surveys are performed to obtain a quick estimate of the radiological situation. The waist-high measurement technique is used. The monitor traverses the radiation zone, monitoring either Predesignated Dose Rates or Predesignated Locations. The gross survey may be done by the constant reading method or the in-and-out method.

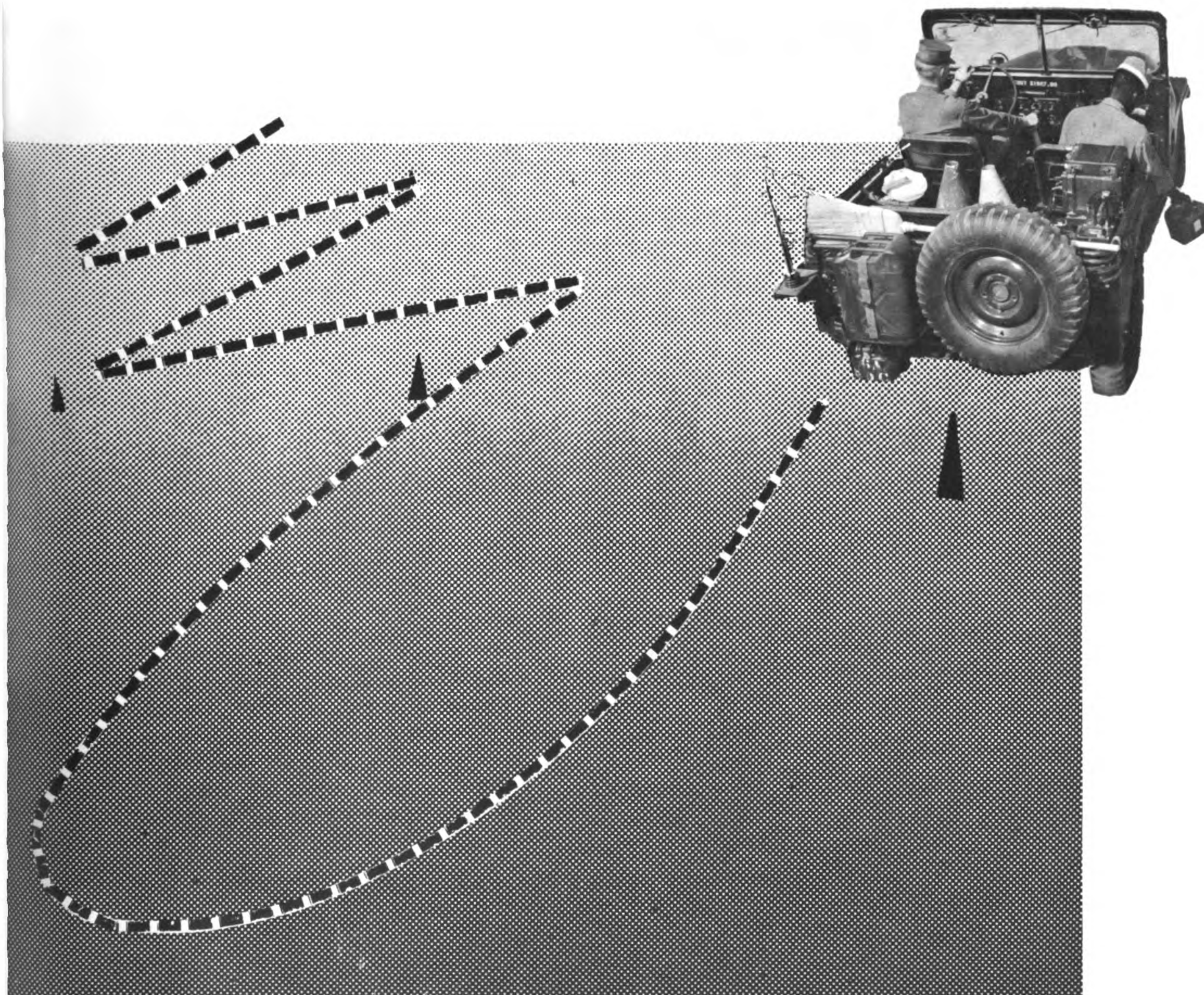
CONSTANT READING METHOD

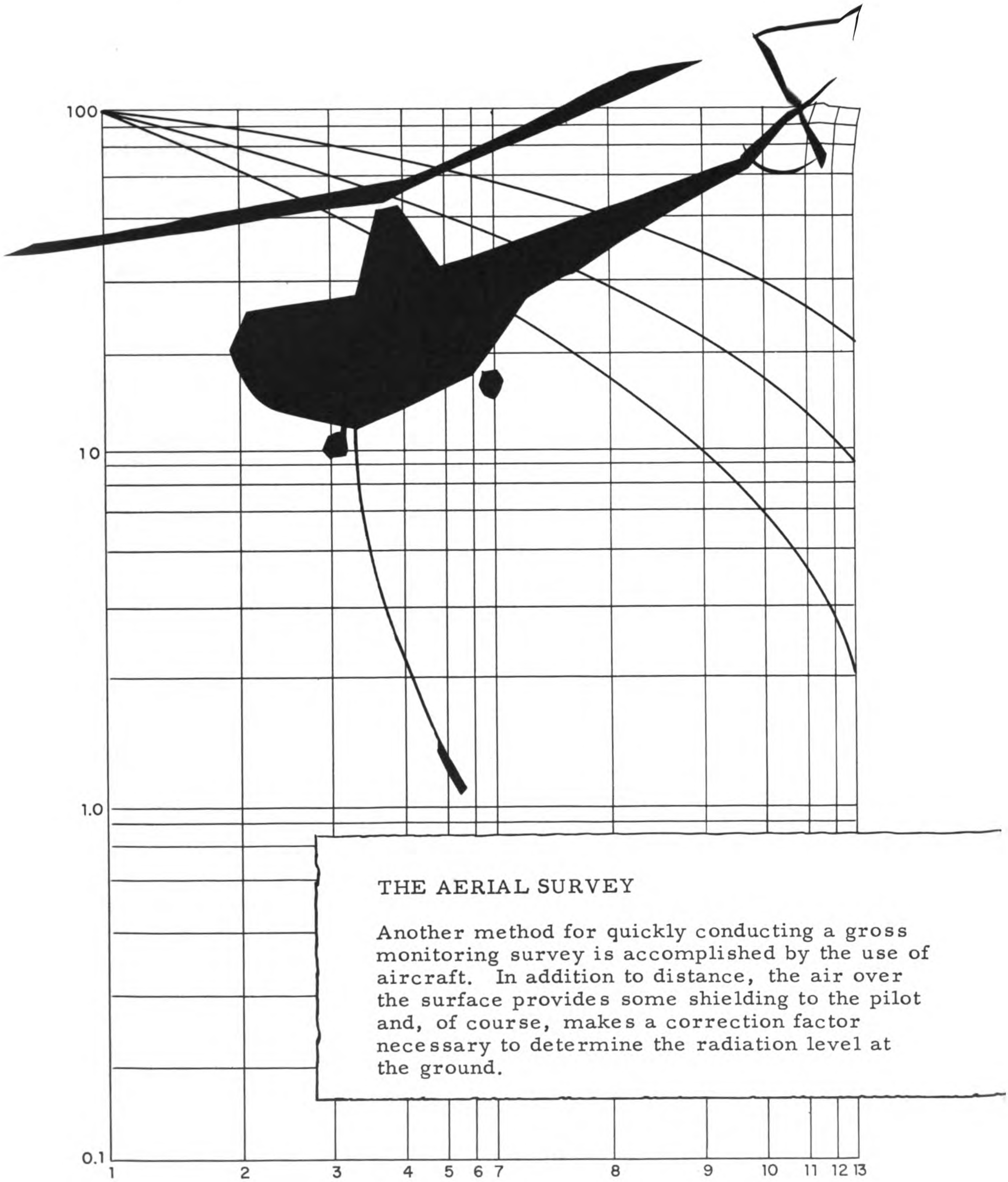
When monitoring areas of moderate radiation intensity (less than 1 r/hr), the monitor proceeds along a predesignated dose rate contour.
Note: The monitoring team will be exposed to this dose-rate for the duration of the survey.



IN-AND-OUT METHOD

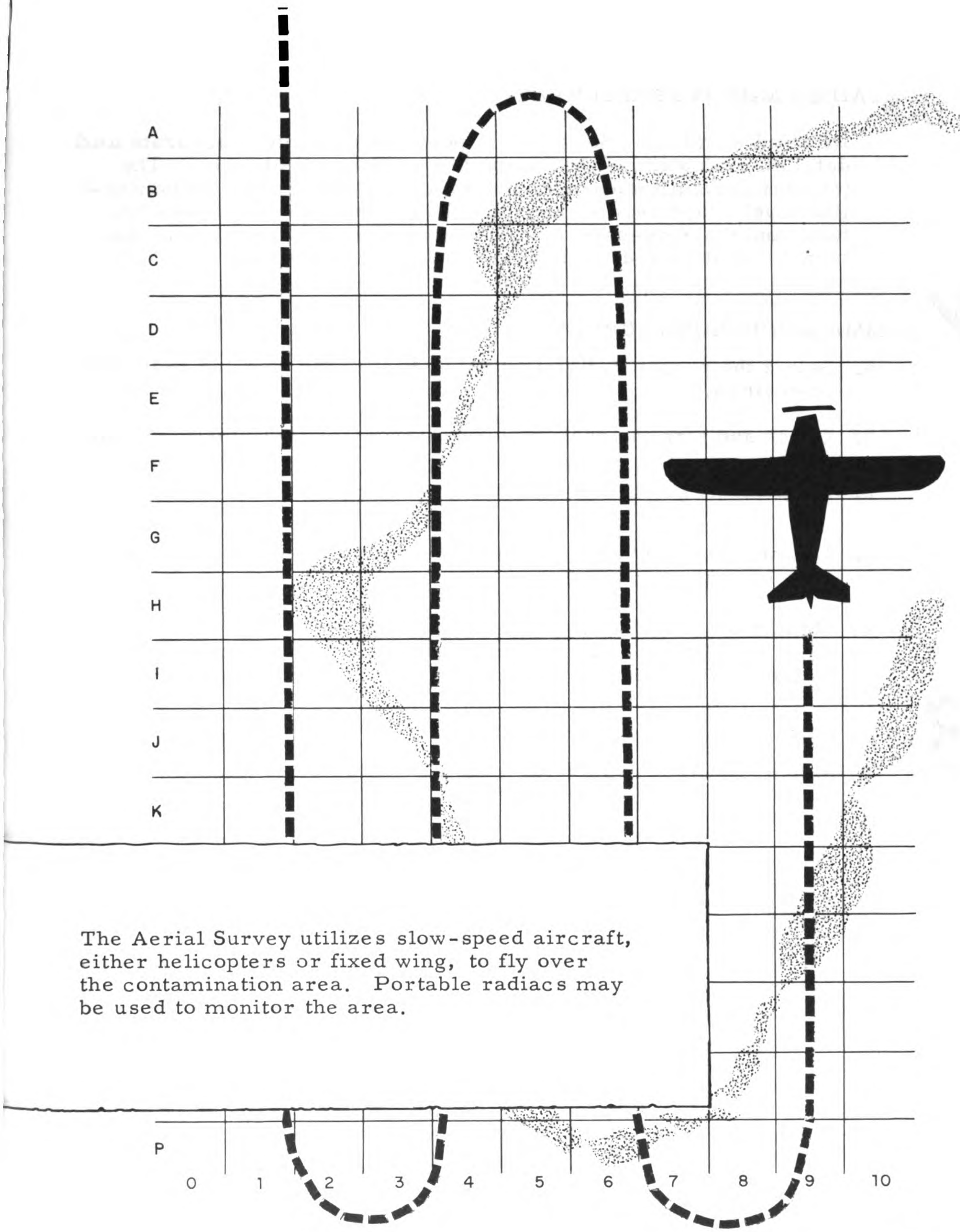
When monitoring areas of high radiation intensity (greater than 10r/hr), the monitor proceeds to a predesignated dose-rate point, then withdraws to a low dose-rate point, repeating this process at several points around the area. Readings are posted as required. Note: The monitoring team will receive less dose than from the constant reading method for equivalent dose-rate contours.





THE AERIAL SURVEY

Another method for quickly conducting a gross monitoring survey is accomplished by the use of aircraft. In addition to distance, the air over the surface provides some shielding to the pilot and, of course, makes a correction factor necessary to determine the radiation level at the ground.



The Aerial Survey utilizes slow-speed aircraft, either helicopters or fixed wing, to fly over the contamination area. Portable radiacs may be used to monitor the area.

DETAILED MONITORING SURVEY

Detailed Monitoring Surveys are performed to afford accurate and detailed evaluation of the complete radiological situation. The monitor carefully measures the radiation intensities, contamination levels, and aerosol hazard. The waist-high, the near-contact, and the wipe-survey techniques are used to assess the external radiation and the internal contamination hazards.

GAMMA MONITORING SURVEY

a. Select the proper radiac that will measure the existing radiation intensities.

b. Check and turn the radiac on before entering the radiation field.

c. Monitor the general or average gamma level.

d. Locate "hot spot" areas where the radiation intensity is greater than 10 times the average.

e. Report or record gamma levels to the nearest radiac-scale reading. Radiacs are nominally accurate to ± 20 percent, so don't waste time trying to read to three significant figures.

BETA MONITORING SURVEY

a. Select the proper radiac to measure the existing intensities.

b. Check and turn the radiac on before entering the radiation field.

c. The BETA RADIATION is measured by (1) monitoring the mixed-radiation field with the beta shield open ($\beta\gamma$ measurement); (2) monitoring the mixed-radiation field with the beta shield closed (γ only measurement); then subtracting the γ reading from the $\beta\gamma$ reading.

d. Monitor the average radiation level. Locate any hot spots. Be sure to measure the β intensity in areas or on equipment where surface contact work will be performed.

e. Report or record readings to the nearest radiac scale reading, to two significant figures.

ALPHA MONITORING SURVEY α

a. Select the proper radiac necessary to measure the existing intensities. Consideration should also be given to the presence of beta radiation.

b. Check and turn the radiac on before entering the contamination area. Always use earphones when monitoring for low intensities.

c. Monitor with the radiac probe about 1/4 inch from the surfaces. Be careful not to contaminate the probe.

d. Monitor all surfaces with which personnel may come in contact.

e. Report or record readings to the nearest scale reading. The unit for alpha monitoring will usually be c/m per unit area or c/m per probe area.

NEUTRON AND HIGH-ENERGY RADIATION MONITORING

γμπδη

Neutron and high-energy radiation monitoring is a complicated procedure and will depend upon the monitoring equipment available. Monitoring procedure for these types of surveys will depend upon the specific instruments used.

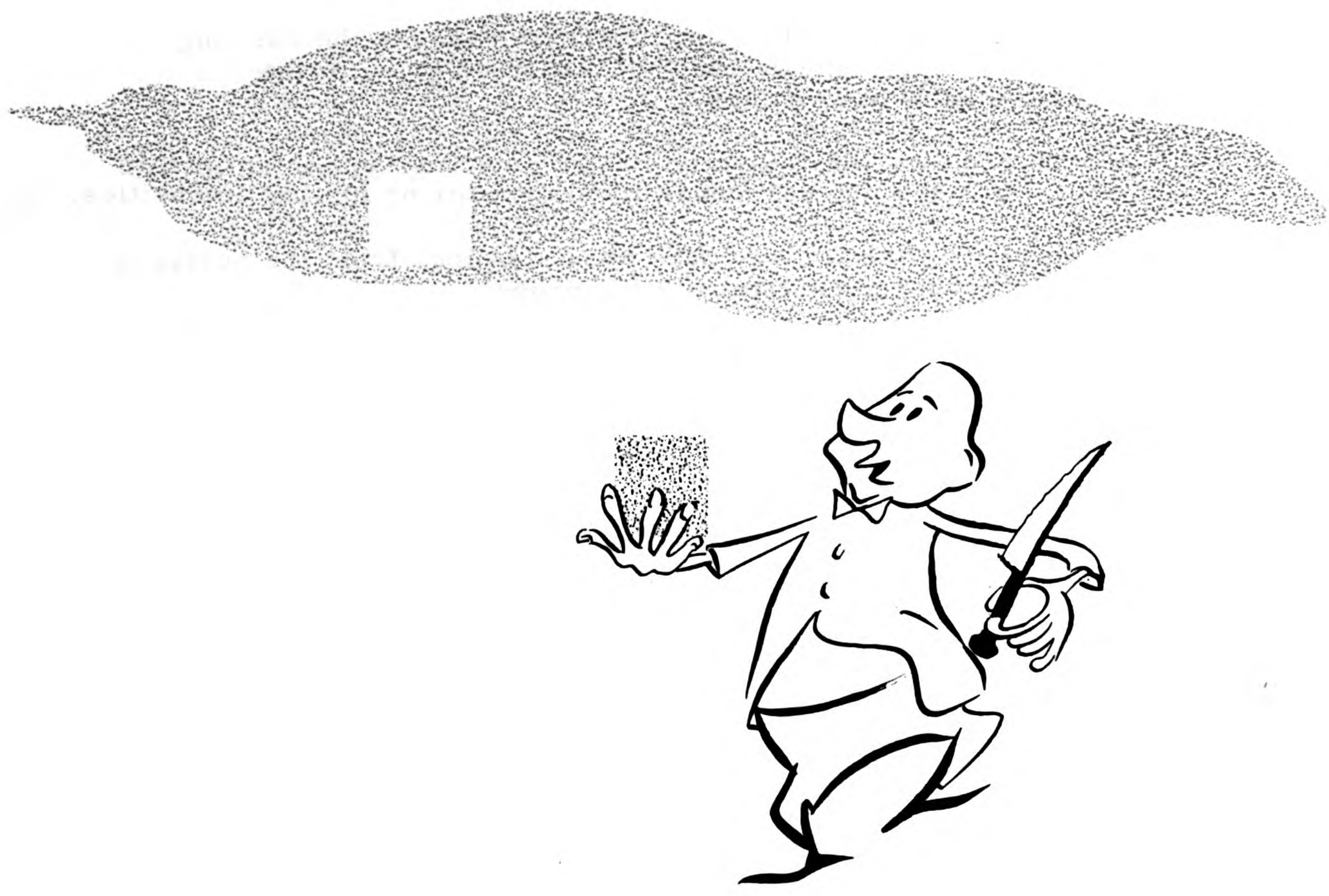
MONITORING REMOVABLE CONTAMINATION

a. Using an absorbent paper (hand towels, toilet tissue, chemical filter paper, etc.).

b. Wipe the surface of the object, using moderate pressure, over an area of 12 square inches.

c. Measure the amount of contamination on the wipe. Use OPEN WINDOW measurements for maximum sensitivity.

AEROSOL SAMPLING



AEROSOL SAMPLING (air sampling) - Airborne contamination must be measured to determine whether respiratory protection is necessary. Aerosol sampling requires:

a. Collecting particles suspended in the air by drawing a known volume of air through a filter.

b. Measuring the radioactivity on the filter.

c. Calculating the amount of radioactive material per unit volume of air.

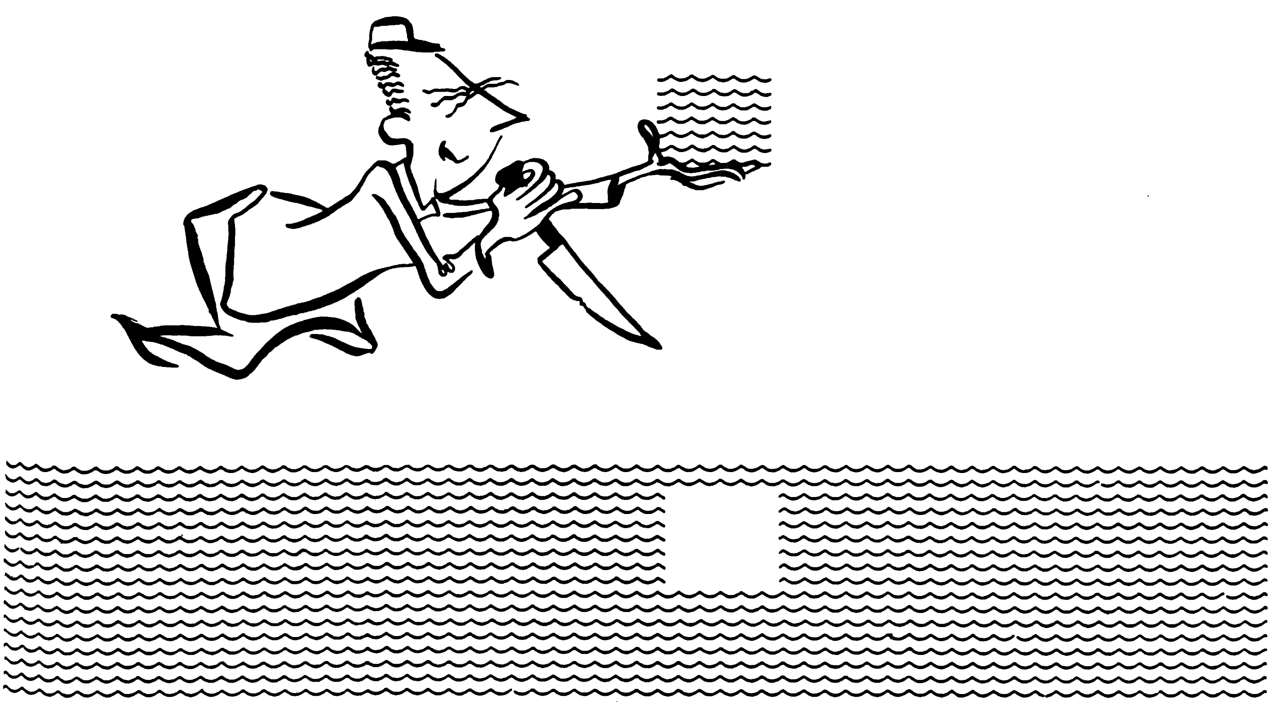
WATER MONITORING consists of:

a. Collecting a representative volume of water (100 to 1000 cc). (Be sure sample bottle is clean!!)

b. Measuring the radioactivity of the sample.

c. Calculating the amount of radioactive material per unit volume of water.

NOTE: Food monitoring follows similar procedures.



PERSONNEL MONITORING to detect body contamination consists of:

a. Selection of proper instruments, (beta shield open for maximum sensitivity).

b. Complete and thorough search of all surfaces, carefully covering those parts of the body and clothing most susceptible to contamination - - hands, face, shoes, sleeves, trousers, etc. (Ear phones are very helpful and are a must when monitoring for α contamination.)

c. Use of a systematic monitoring pattern, i.e., ① the hand first ② working to the face and head ③ proceeding down the body to the feet.

> Personnel monitoring may also refer to the use of film badges and pocket chambers to detect external radiation exposure.

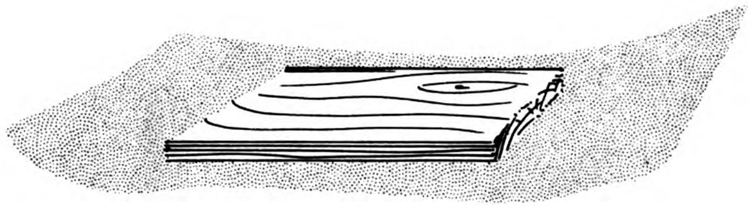
MONITORING FOR ARRIVAL OF FALLOUT can be done by any of the three steps outlined on this and the following page:

▶ Periodic monitoring of an outside, predesignated clean area where there will be no redistribution of previous contamination.

A rise in radiation level will be due to (a) fallout coming down or (b) a contaminated cloud passing overhead. A wipe survey will confirm arrival of fallout.

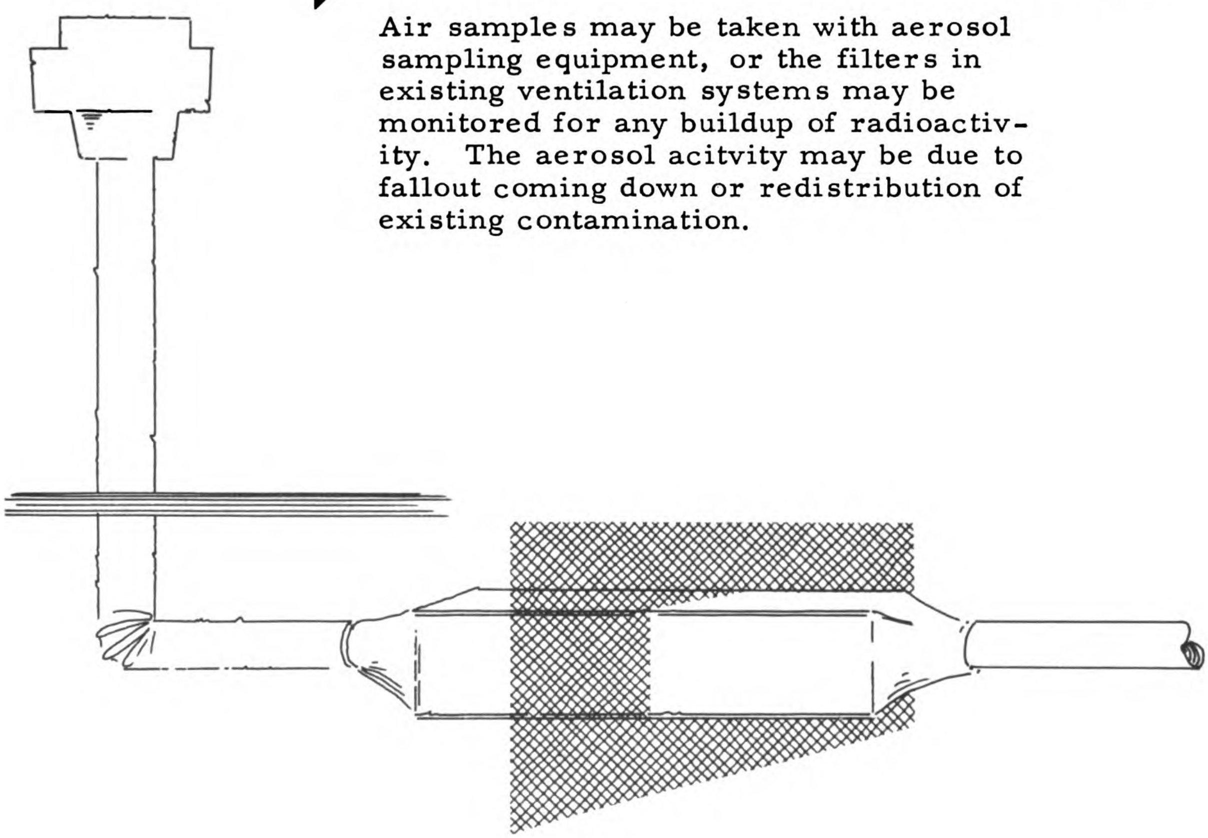
Collecting fallout on a greased board (about a foot square) laid in the open.

If the local background is high, carry the board elsewhere for measurement.



AEROSOL MONITORING OF THE OUTSIDE AIR

Air samples may be taken with aerosol sampling equipment, or the filters in existing ventilation systems may be monitored for any buildup of radioactivity. The aerosol acitvity may be due to fallout coming down or redistribution of existing contamination.



RADIOLOGICAL SITUATIONS

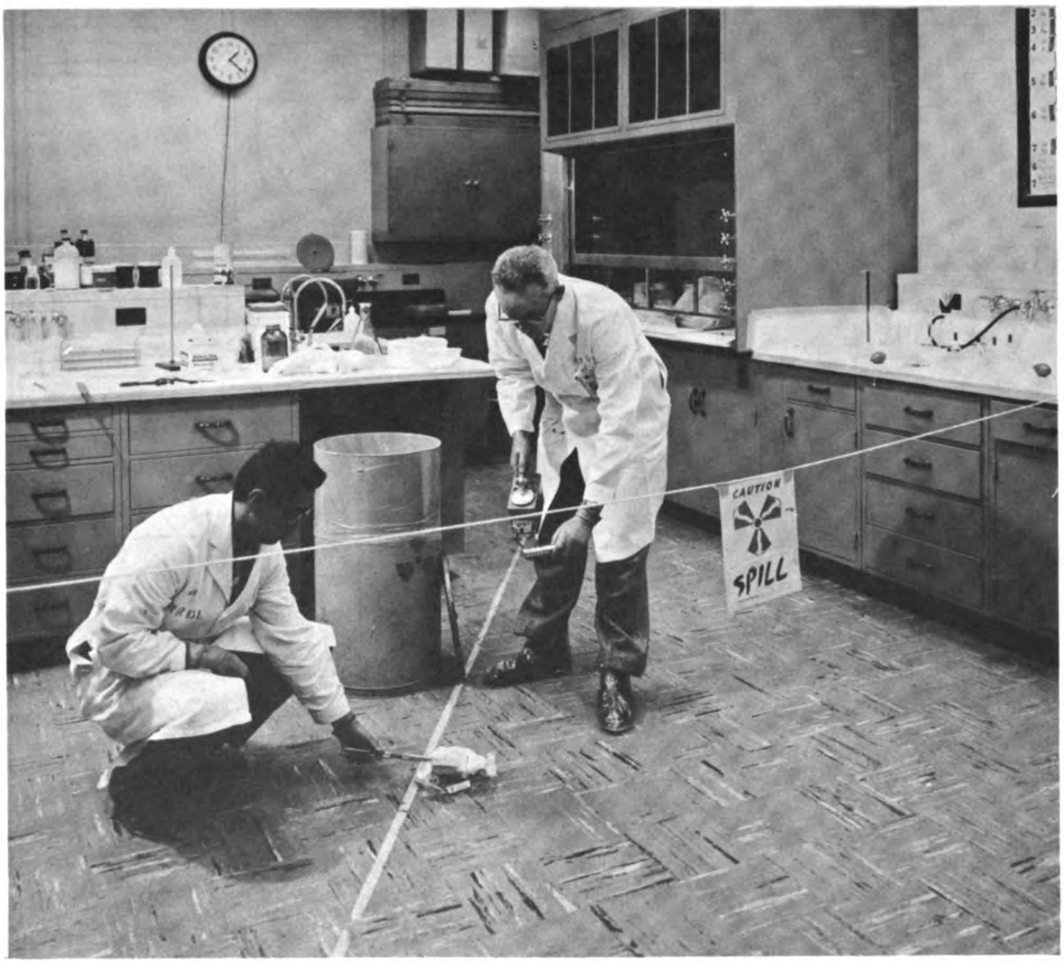
RADIATING MACHINES AND SEALED SOURCES

Monitor the radiaton field to establish the stay time. A person's radiation exposure stops when he leaves the radiation area. Sealed sources should be wipe-tested - lest their transfer lead to a contamination problem.

1

Monitor for removable contamination (may be masked by the gamma background). Prescribe the dress and control the activities of personnel to minimize the spread of contamination and prevent its inhalation and ingestion.

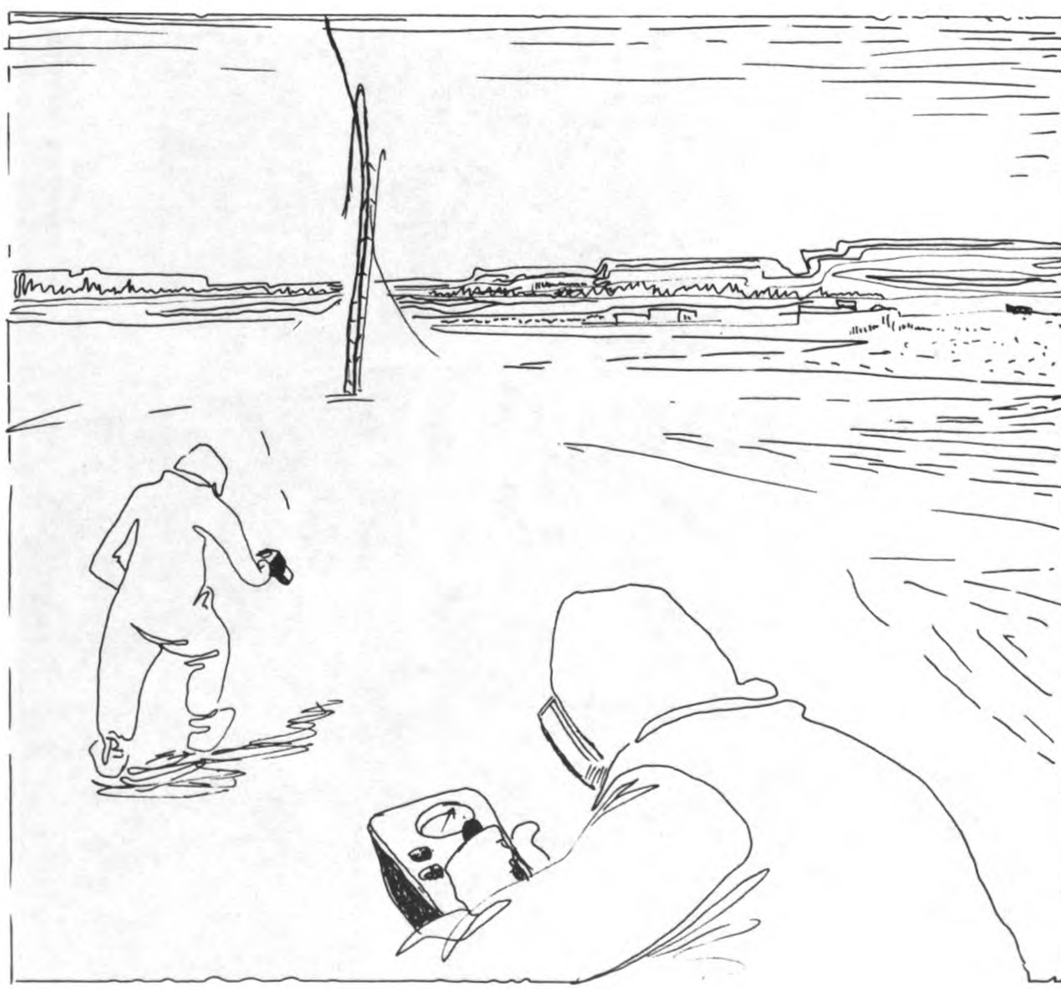
2



MORE THAN 100 MILLICURIES OF $\beta\gamma$ EMITTERS

Gross gamma monitoring is required to establish the permissible stay time. Detailed monitoring is required to establish the necessary contamination control procedures, i.e., protective-clothing requirements, handling equipment, etc.

3

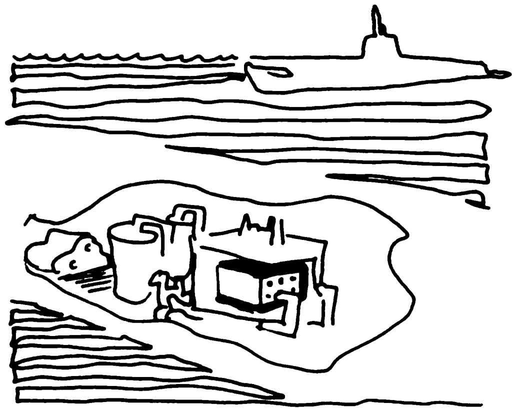


ANY ALPHA AND LESS THAN 10 MILLICURIES PER SQUARE YARD OF β EMITTERS

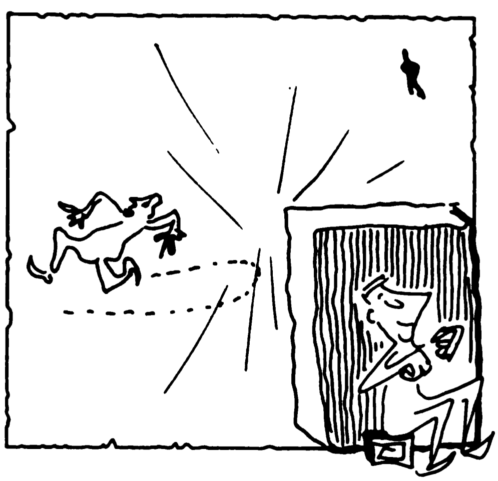
Detailed monitoring is necessary to determine the danger of internal body contamination. Stringent controls must be placed on personnel to prevent inhalation and ingestion and to prevent the spreading of contamination to uncontrolled areas.

4

SUMMARY



The information presented thus far indicates that the increased production of radioactive material throughout the world results in the presence of undesirable sources of radiation. These radiations must be detected and controlled, for they can produce harmful biological effects.

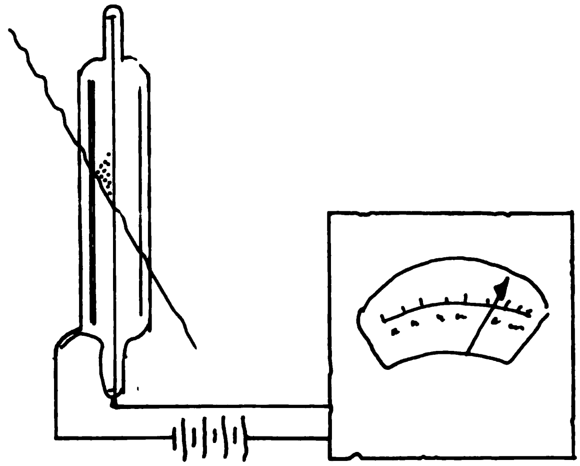


Sufficient specific information has been given to show that the average civilian or military person can prepare himself to operate effectively in the field of radiological safety if it becomes necessary.

Rad-safe measures have been described showing that radiological safety is not an end in itself but is a means to control situations which might otherwise be harmful. These measures will permit work to proceed in areas where long delay in production, either military or civilian, might be disastrous.

The principles of fission and fusion have been illustrated. The various types of protection against harmful radiations have been discussed.

Material has been presented on the use of radiacs, which are the tools of monitors. The physical measurements have to be translated into terms of danger to health.

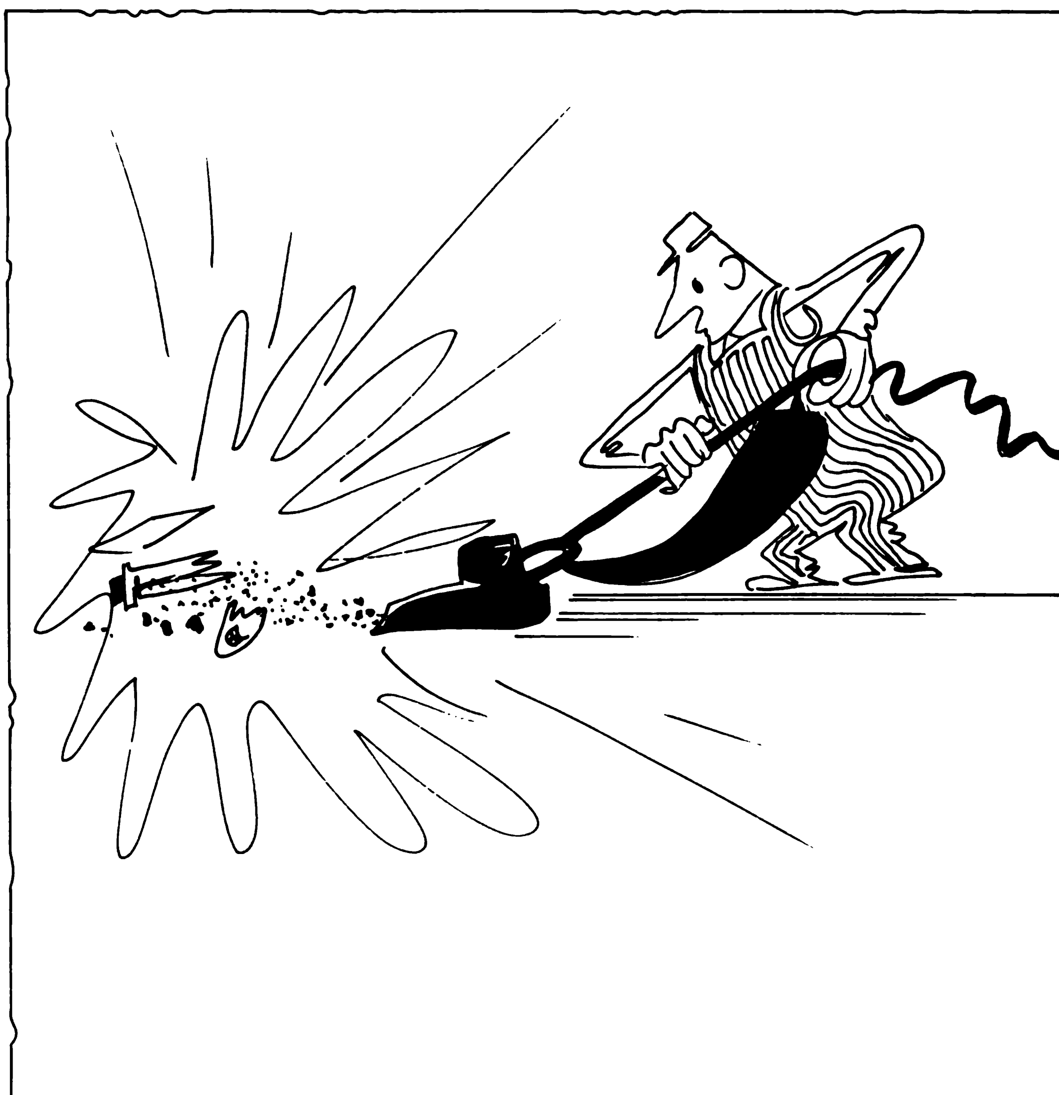


The radiation monitor must be familiar with dosage control for external radiations and employ techniques involving time, distance, and shielding. He must understand control of internal contamination and employ protective techniques against inhalation, ingestion and absorption of radioactive materials into the body.

Methods of marking radioactive contamination, zone control of contamination, decontamination procedures, and protective clothing and equipment have been cited as necessary to radiological safety and to the monitor's work.

Whatever the situation - radiation with little contamination, contamination without much external radiation, or high hazard from both - proper instruments with technical knowledge and some COMMON SENSE can minimize the danger. The rule is:

NO UNNECESSARY EXPOSURE !!



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